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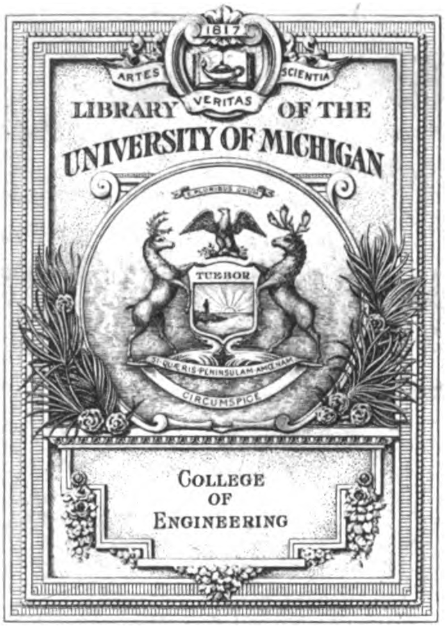
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GENERAL ELECTRIC REVIEW

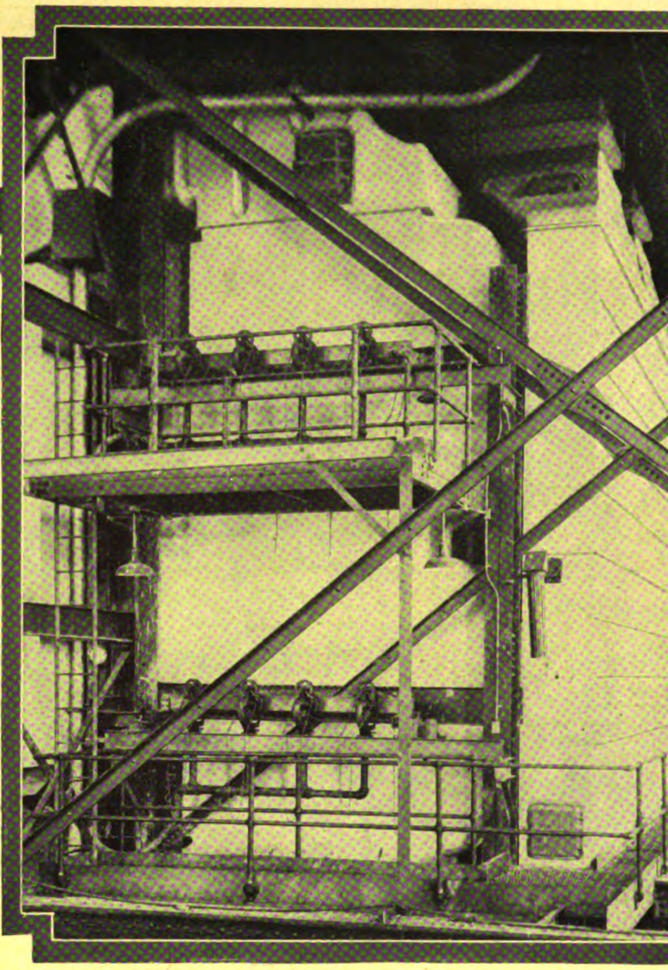
JAN 15 1930

VOL. 33, No. 1 JANUARY, 1930

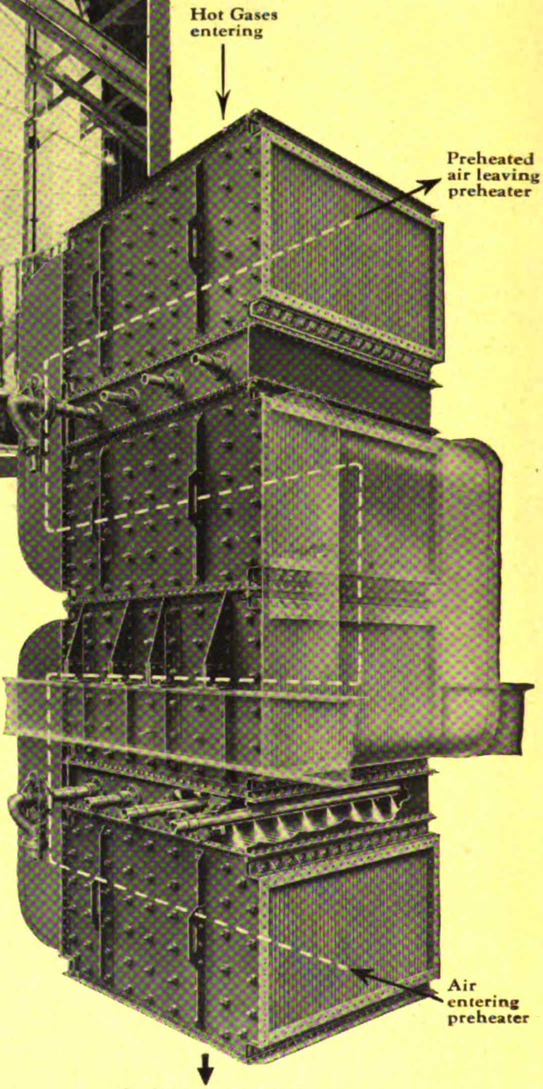
208,000 KILOWATTS FROM ONE TURBINE-GENERATOR UNIT

The record-size triple cross-compound unit installed in 1929 at the State Line Generating Station, consisting of one high-pressure and two low-pressure turbine elements, and three main generators and two service generators

In This Issue: *A Review of the Progress Made in the Electrical Industry, and the Advancement in Radio Reception During 1929*



Complete 51,000 sq. ft. Foster air preheater, consisting of 16 interchangeable sections. Gases leaving the heater, pass upward to the stack through the duct shown to the right of the air heater sections.



Arrangement of four sections of the Foster Air preheater, placed one above the other. The dotted line with arrows, indicates the path of the air flowing through the sections. Gases pass vertically downward through the heater.

Four of these groups placed parallel comprise the complete air preheater shown above to the left.

Foster Air Preheaters

More than 310,000 lb. of air per hour are heated from 100 to 519 deg. F., by each of the Foster air preheaters shown above.

Foster plate type air preheaters are composed of interchangeable sections. The sections, consisting of parallel steel sheets, are completely assembled at the shops, before shipment. At point of erection, each section is bolted into position.

The interchangeable sections, making up the complete heater may be arranged for either series or parallel flow of gases and air. Their arrangement depends upon station conditions and requirements to be fulfilled.

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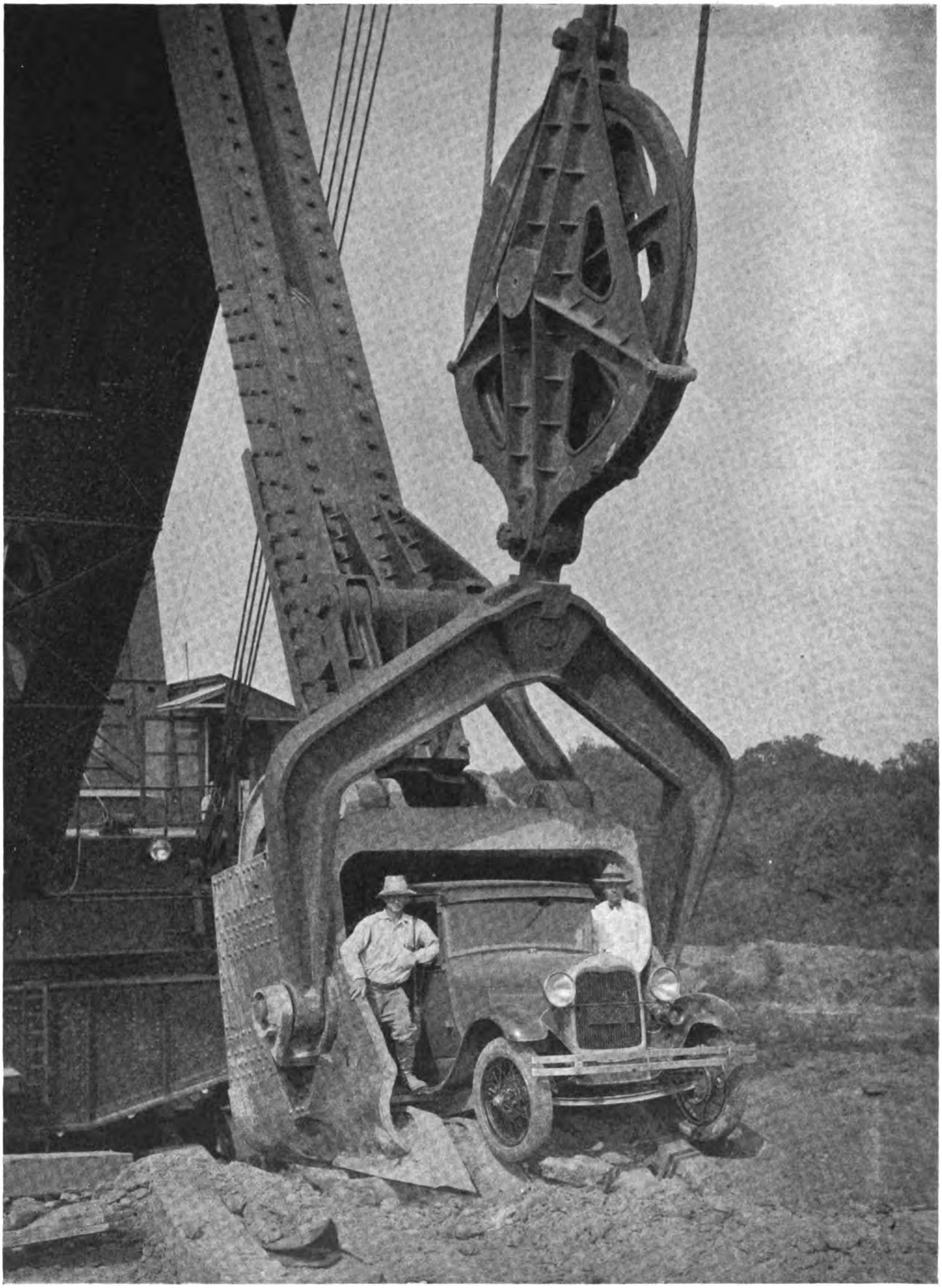
The Contents of this Magazine are indexed annually by the Publisher,
monthly by *INDUSTRIAL ARTS INDEX*, and weekly and annually by *ENGINEERING INDEX*; and abstracted monthly by *SCIENCE ABSTRACTS*



THE LARGEST SHOVEL IN THE WORLD

A graphic illustration of the size of the bucket on this 4500-hp. 1600-ton coal-stripping electric shovel which under the control of one man will scoop up 15 to 20 cu. yd. of material, raise it 85 ft., dump, and return to start the digging operation again in less than one minute

GENERAL ELECTRIC
REVIEW

Vol. 33 January, 1930 No. 1

EDUCATION BY RADIO

The U. S. Government, through the agency of the Secretary of the Interior, has appointed an Advisory Committee on Education by Radio to make a national survey of educational broadcasting and to advise on its possibilities for the future. This seems an excellent plan because if Education by Radio is to be a success it must be divorced from the controlling influence of any specific educational or commercial institution, while being free at all times to call upon them and all other national resources for coöperation. Further, should the government so desire, there is always the possibility that special wavelengths and other privileges of the air can be assigned to education as the work grows in importance.

It is always easier to criticize school and college curriculums than to make intelligent suggestions for their improvement. A recognition of the fact that this new committee has a hard task ahead prompts us to say that we believe the possibilities of Education by Radio are immense and that in time it can be built up to be a power throughout the land.

Woodrow Wilson on one occasion wrote: "The great voice of America does not come from the seats of learning. It comes in a murmur from the hills and woods and farms and factories and the mills, rolling and gaining volume until it comes to us from the homes of common men. Do the murmurs echo in the corridors of the universities? I have not heard them."

We think that Education by Radio can make this great voice more articulate and more intelligible and make many widely scattered entities mutually useful. This new form of education outside schools and universities can enrich the lives of many who have not trod the corridors of our universities and can certainly add something to the lives of all.

The general problem is full of interest because it is an almost virgin field of human endeavor. A problem well stated is half solved, but if we see things correctly it is going to take a long time before this problem can be even partially stated. The only way that will lead toward success in so new a field is through experiment. Experience based on experiment should eventually lead to an intelligent statement of the problem.

It must ever be remembered that education does not consist of pouring facts into a skull. A skull too full of facts has the spark of originality quenched. All that education can hope to do is to develop cerebral cortex and the right way to start is to awaken interest. We feel that Education by Radio can stimulate numerous interests in many people and after having awakened these interests can continue to help people to help themselves.

If Education by Radio is to have an early success, some fundamentals must be understood. In the first instance it must be recognized that it is a new thing and present methods may not be applicable. In some phases of educational work, radio methods will be better than older methods. There will be the ever present question—What next? In this period of embryo development certain new things will appear, which will lead eventually to unthought-of results. It is these novelties that must be followed up. If we cast an unknown seed into the ground it may be interesting to speculate what flower and what fruit it will bear, but it is useless. So it is with Education by Radio. We must plant the seed first and watch for the fruit. To give an analogy: when crossword puzzles were started, who could have foretold the vogue they would attain—who could picture the fruit? In all probability crossword puzzles led a greater number of people to use dictionaries than ever before. Many used them that had never seen and certainly never used a dictionary in their lives.

In trying to visualize how things may work out, let us imagine a particularly novel subject being broadcast. The first thing that will happen is that it will stimulate interest in a certain group of people. Then there must be some response from at least part of the group to the educational center so that it can know the results of its efforts. Many useful suggestions will be sent in. If the subject is chosen wisely it will go beyond stimulating mere interest; it will also stimulate effort on the part of the listeners and make them look things up. The talk or lecture should not always give answers to the questions raised but should require a reasonable amount of work. In some instances the student should be told where to find desired knowledge. In other cases it would be well to let the student do a little real searching. In this way our libraries might become a greater asset than at present.

Research and experimental work must be done in determining the groups of people to be educated, the subjects to be given, and the selection of speakers.

The question will be ever present—Whom do we want to educate? First thoughts would lead one to the idea that this form of education would be unsuitable for children, on the plea that children need the personal touch, but on second thoughts, when we remember the experience of educators with movies in schools we can feel assured that radio in schools will do at least as much to stimulate interest and hold the attention as the movies and phonographs have done. Possibly in schools and colleges radio will always be only a supplemental help. One thing seems certain, *i. e.*, that in the future some master minds—some outstanding educators—will, through the medium of radio, be able to reach vastly more students than today, to the great benefit of the students.

The subjects that should be broadcast to our multigrouped audiences are bewildering in number. Indeed, they might be likened to the charms of Cleopatra—for "age cannot wither them, nor custom stale their infinite variety."

To make a specific suggestion, we should like to see any subject broadcast to children that would awaken in their minds, during the impressionable age, an interest in Nature. We mean anywhere and everywhere in the whole range of Nature. Make children understand that they are all members of a great universe, and that every natural thing around them is there for their interest if they will only use the intelligence and patience to examine it. Early impressions are the foundations of education, and as such are the most important things in the world. They can lead to achievements or uselessness, to good or evil, to failure or success.

Another field from which we should definitely expect rich fruit is the "Mechanics' Institute" type of man. There are in almost all places artisans and workmen who are honestly anxious to improve their technical knowledge. They are willing to make great sacrifices to attain this knowledge. It would not be surprising if radio in the future largely supplanted the night school with a distinct advantage to people who are tired after a hard day's work. They would not have to sit in stuffy classrooms or consume time in going and coming.

You cannot acquire character by studying ethics but you can acquire and develop character by engaging in some useful occupation. The education of the man who uses his hands has always paid handsome dividends and always will. The nation that realizes this has the future in its grasp. We feel that Radio Education will pay dividends to the nation.

It would be futile to attempt to write a list of subjects that should be broadcast. It would, perhaps, be easier to write a list of subjects that should not be broadcast.

There are, however, some subjects, possibly outside the most apparent, that would take a lot of drabness out of the average life, in both town and country. Let us mention astronomy. Perhaps interest could be stimulated in this all-absorbing subject by starting with seasonal astronomy. We can visualize some specially gifted person being asked to broadcast the position of the constellations, say once a month. His listeners sit in far-flung homes with pencil and paper before them. Then he instructs them to make a cross in the center of the paper, and, using the clock diagram method, asks them to make another mark at such and such a distance, say in the direction of eleven o'clock, and so on till the completed diagram represents the constellation most prominently visible at the time. When his audience goes out afterward, at the time and place appointed, to find and view their newly-learned map of the heavens, many of them will have a new interest in life.

We should judge that talks on scientific subjects would be specially popular, but the popularity of any subject will largely depend upon the gifts of the speaker. Some have the genius to make people think. We have in mind an expression of Sir Oliver Lodge when he said the atoms in a lump of copper are moving in a vacuum! Of course he is right, but have you ever thought of it in that way?

In all probability short biographies of some of the great men of the world, in all walks of life, would have a broad appeal and large educational value.

We imagine some people will develop an extraordinary genius for broadcasting educational subjects and that the possibilities will grow all the time. Many semi-educational subjects that will suggest themselves will help by putting new things into peoples' heads and enable them to get more out of their leisure hours.

The subject is so large and holds such possibilities that we shall watch its development with keen interest.

It must not stop at broadcasting knowledge already accumulated in books but must distribute new knowledge as acquired. It can be useful to every one. It must be remembered that education is a debt due from the present to the future generation. Utilitarian subjects may form the bulk of the material broadcast, but we hope that we may have some of "that education, that culture, which comes from the highest quality of imagination exemplified in the poets."

J. R. H.

Developments in the Electrical Industry During 1929

By JOHN LISTON
General Electric Company

AS a result of the increased activities in industry, transportation, and communication, which characterized the year 1929, the volume and the dollar value of electrical equipment produced were greatly in excess of the maximum record of any former year. The pragmatic worth of research was graphically indicated by the fact that more than twenty per cent of the total income received was for electrical apparatus which as recently as a decade ago was either unknown or of negligible importance commercially.

Two record-sized turbine-generators were completed and placed in service; a 208,000-kw. cross-compound unit and a 160,000 kw. tandem-compound unit, each the largest of its type so far constructed. Of exceptional interest, because of its potential influence on the future of central-station practice and possible economies, was the growth in the use of turbines operating at steam pressures of 1200 lb.; the aggregate capacity of such machines completed or under construction being greater than the combined capacities of the preceding six years.

A third large passenger ship, with electric propulsion, named *Pennsylvania*, was completed for the Panama-Pacific route, and work on similar propelling equipment for coastwise and transoceanic liners was in progress at the close of the year. Ingenious applications of turbine-generators were made to increase the power available for propulsion on ships equipped with reciprocating engines.

The electrification of railways proceeded at an unprecedented rate and new records were achieved in the number of electric and oil-electric locomotives built. The gasoline-electric type of railway car was provided with increased power, while the tendencies in street-railway operation were generally along the lines of lighter construction and the use of improved forms of electro-pneumatic and magnetic braking in order to maintain adequate schedules despite the growing density of urban traffic.

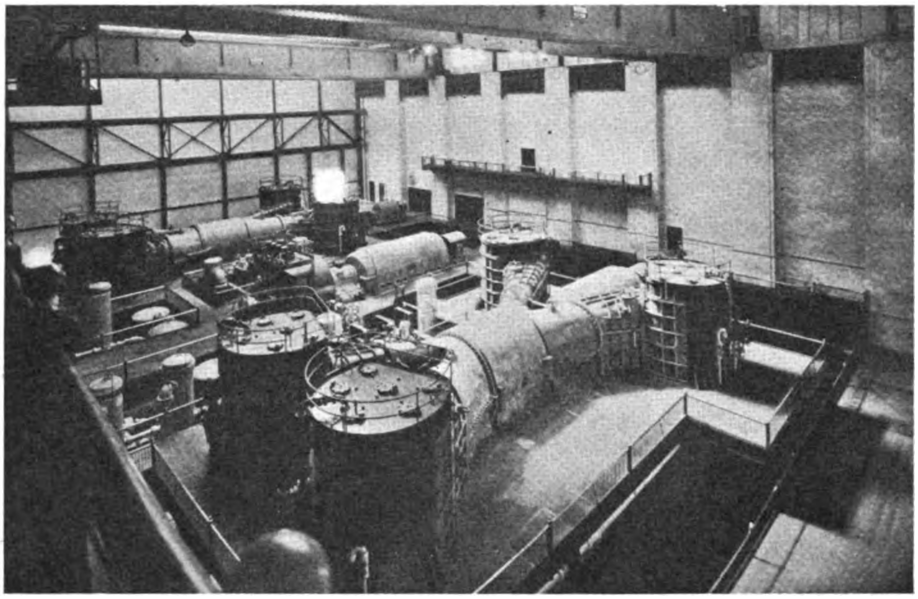


Fig. 1. Turbine Room of the State Line Generating Company Near Chicago, Showing the Three Elements of the 208,000-kw. Turbine-generator

With more than 10,000 miles of airways and about 260 intermediate landing fields provided with guide beacons and ground lighting, the United States Department of Commerce was enabled to decide on practical standards for airway and airport lighting systems. It is expected that more than 2000 miles of additional airways will utilize this standardized equipment.

Further developmental work was done on the radio altimeter designed to minimize the hazards of blind flying while the new magneto compass, with special alloys in the magnetic circuit, and the electric fuel supply and engine temperature indicators were produced on a commercial basis.

Investigation in the field on full-sized transmission lines with a portable lightning generator and the cathode-ray oscillograph revealed the fact that the choke coil, used for years in lightning protective systems, was of little actual value in this service and its use was discontinued. The photo-electric tube was developed commercially for the control of electric circuits through variations in the intensity of light and the Thyratron was practically applied in the control of lighting systems.

There was a notable extension of the use of the mercury-arc power rectifier, especially in railway substations, and the voltage and the unit and aggregate capacities of this type of equipment were carried beyond previous maximums.

Two outstanding accomplishments in lighting were the production of the sunlamp which serves as a safe source of ultra-violet rays, and the water-cooled lamp which makes feasible a high intensity of illumination combined with low temperatures. The trend toward the concentration of greater wattages in single street-lighting standards and higher intensities of illumination for business streets was exemplified by a recent installation in Detroit which utilizes 2000-watt Mazda lamps and gives an illumination of about 1900 lumens per linear foot of street.

In presenting a review of these and many other developments which occurred during the year, all the apparatus referred to are products of the General Electric Company. These cover such a wide range that the references will serve as an indication of the tendencies in design and construction as well as the general progress in the electrical manufacturing industry as a whole.

TURBINES

The year was marked by the placing in commercial operation of three turbines of a capacity larger than heretofore produced, each of a radically different design, and also by a notable increase in the use of 1200-lb. steam pressure.

Turbines for a steam pressure of 1200 lb. totaling more than 500,000 kw. (Fig. 2) are now installed or under construction. No unusual difficulties, which could be attributed to the high steam pressure, have been experienced with the turbines in operation. In fact, the units are started and stopped and otherwise handled with the same ease as large turbines operating at lower pressures.

New Vertical Compound Type

Several of the recent 1200-lb. pressure turbines are of a new type and are designated as "vertical-compound turbines." Two units of this type (Fig. 3) of 50,000-kw. capacity each are being constructed for the Pacific Gas and Electric Company and two 25,000-kw. units for the Jersey Central Power and Light Company. They have the high-pressure element, consisting of a turbine and generator operating at 3600 r.p.m. and comprising approximately 25 per cent of the total capacity of the unit, mounted on top of the generator of the low-pressure element which operates at 1800 r.p.m. This arrangement conserves space, saves some piping and one foundation, and permits the use of one set of air coolers for both generators.

A 110,000-kw. turbine designed for 1200-lb. pressure is being built for the Ford Motor Company. This machine (Fig. 4) is also one of the vertical-compound type, but it is unlike the units just referred to in that both elements operate at 1800 r.p.m. and the high-pressure turbine is mounted on top of the low-pressure turbine. The generators are duplicates and the generator driven by the high-pressure element is mounted directly on top of the generator driven by the low-pressure element. Air coolers will be built integral with the generators and will be connected so that the heat losses of the generators will be recovered and returned in the feed water.

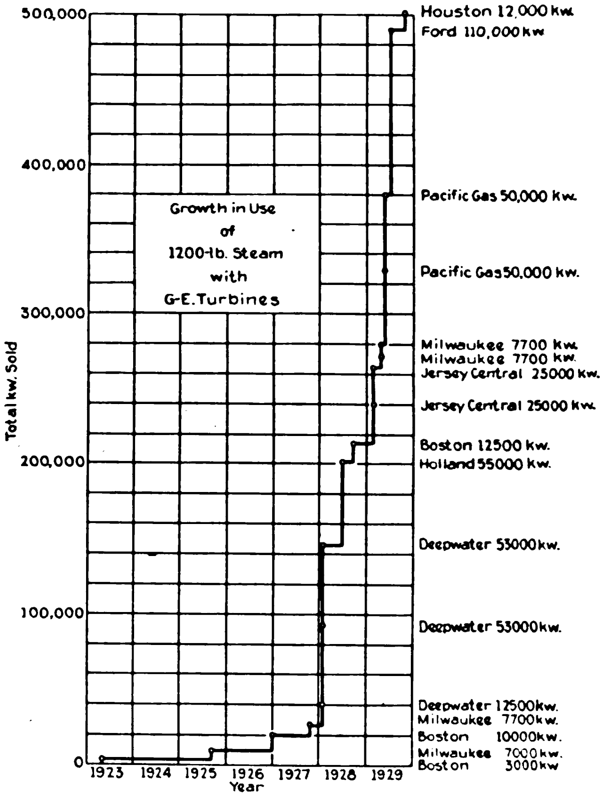


Fig. 2. Growth in Use of 1200-lb. Steam Turbines

Steam will enter the upper or high-pressure element of the turbine at 1200 lb. pressure and 725 deg. F. total temperature, and it will exhaust into two adjacent steam reheaters in which its temperature will be raised to 550 deg. F. Then the reheated steam will enter the double-flow low-pressure element of the turbine and will exhaust at one inch back pressure.

A 12,000-kw. turbine designed for the throttle pressure of 1300 lb. for the Houston Lighting and Power Company will exhaust at about 380 lb. into the station header that supplies steam to four other turbines, ranging from 20,000 to 35,000 kw. in capacity. Superimposing and base-loading a high-pressure installation of this kind on an existing low-pressure station results in obtaining the additional capacity at a very low heat rate. Thus, to obtain 12,000 kw. from this 1300-lb. turbine exhausting into the low-pressure steam mains, it is necessary to burn only about one-third as much coal as would be required were the additional output obtained from a 12,000-kw. turbine operating on the present steam conditions.

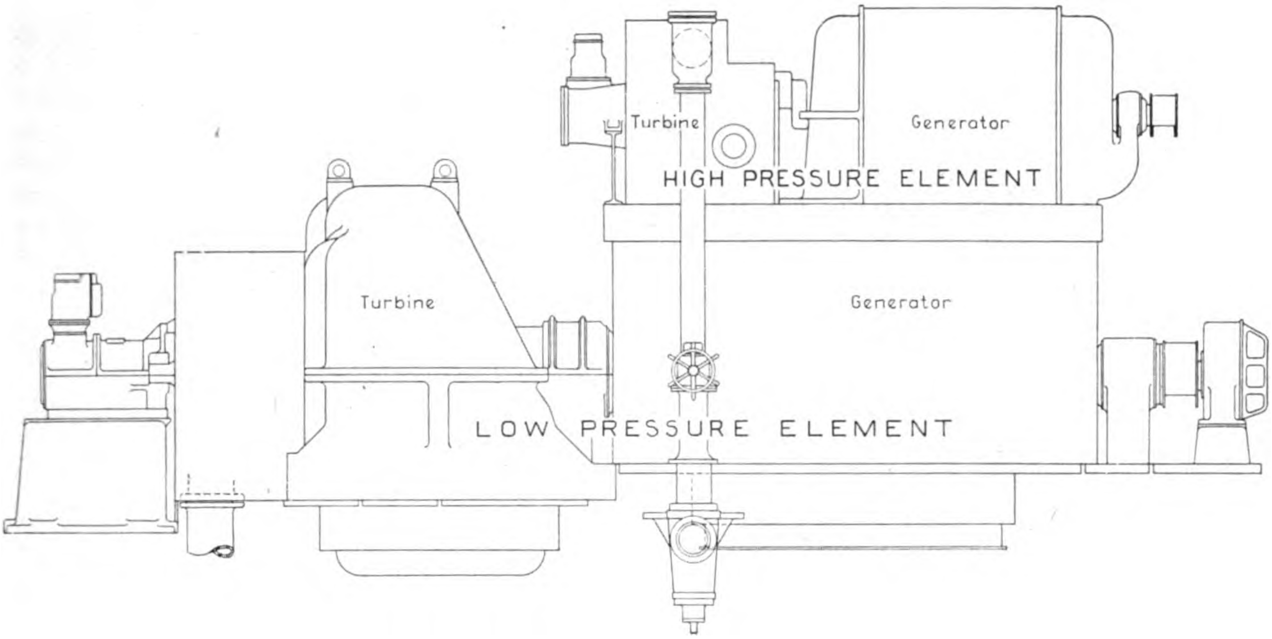


Fig. 3. 50,000-kw. 1200-lb. Vertical-compound Turbine-generator Set with 3600-r.p.m. High-pressure Element Mounted on Top of Generator of 1800-r.p.m. Low-pressure Element

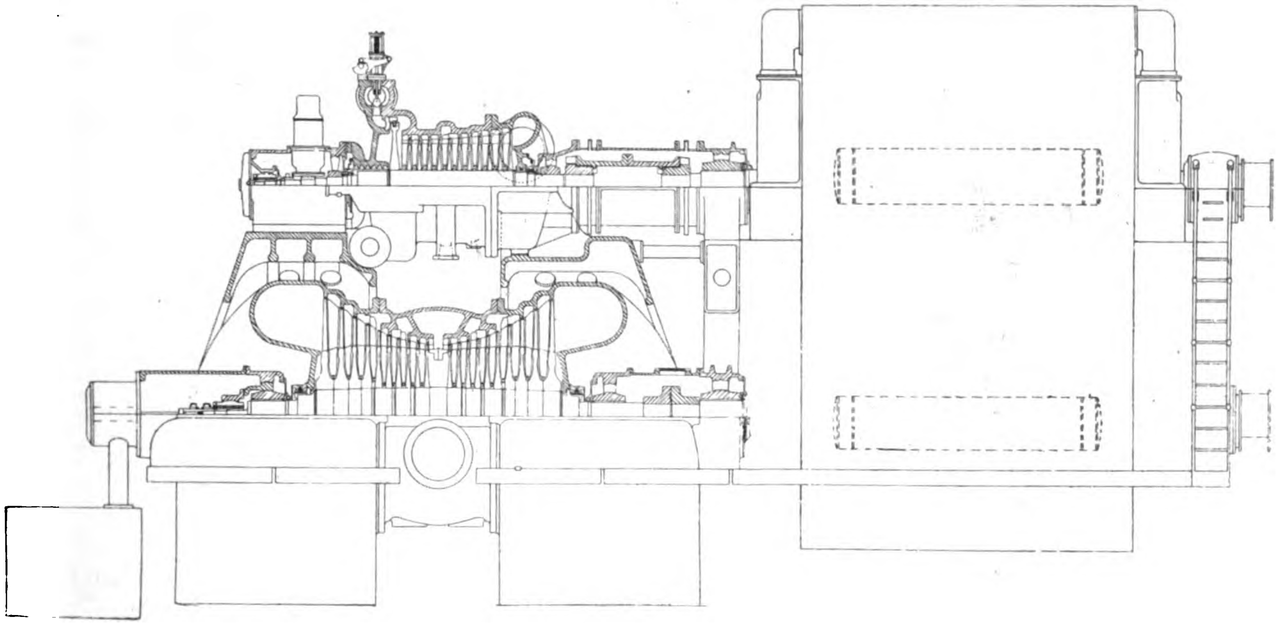


Fig. 4. 110,000-kw. 1200-lb. Vertical-compound Turbine-generator for the Ford Motor Company. Both elements operate at 1800-r.p.m. and have duplicate generators with integral surface air coolers

Single-cylinder Turbines

The largest single-cylinder turbines for both 1500 and 1800 r.p.m., corresponding to 25 and 60 cycles, are under construction for the Buffalo General Electric Company. The 1500-r.p.m. unit is rated 75,000 kw. at 0.8 power-factor; while a unit previously placed in operation is rated 75,000 kw. at 0.9 power-factor. The 1800-r.p.m. unit has a capacity of 80,000 kw. at 0.8 power-factor, and therefore exceeds by 5000 kw. a 75,000-kw. unit being built for the Glenwood Station of the Long Island Lighting Company. The 80,000-kw. unit is designed for steam conditions of 425 lb., 750 deg. F. total temperature and one inch back pressure.

Large Units

Three more 50,000-kw. 1200-r.p.m. turbines were built for the Detroit Edison Company, which now has six units of this type in the Trenton Channel Station, two in the Delray Station (Fig. 5), while construction is proceeding on units for the Marysville and Delray stations, making a total of ten 50,000-kw. machines soon to be in service for this company.

generator of this set has a double winding and a total capacity of 160,000 kw., and is the largest generator of any type ever built.

The 208,000-kw. triple cross-compound unit built for the State Line Generating Company (Fig. 1) has now been in commercial operation for about six months.

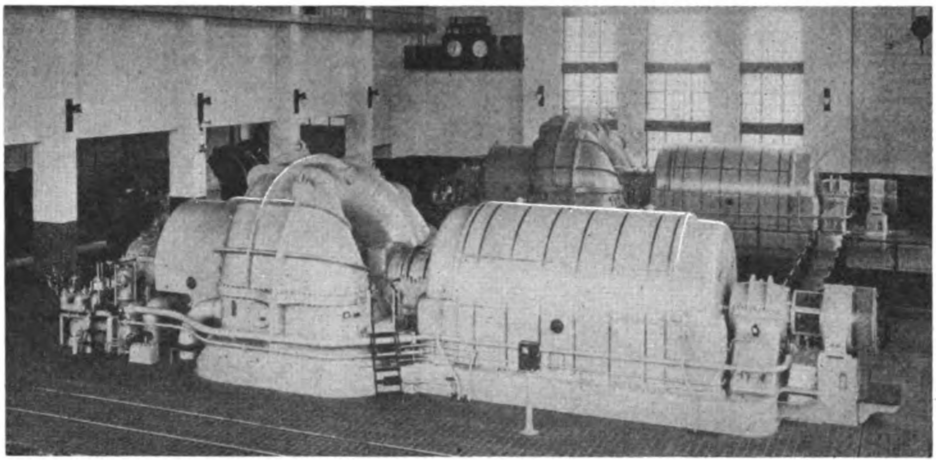


Fig. 5. The Delray No. 3 Power Plant of the Detroit Edison Company Showing Two 50,000-kw. 1200-r.p.m. Turbine-generator Sets Recently Installed

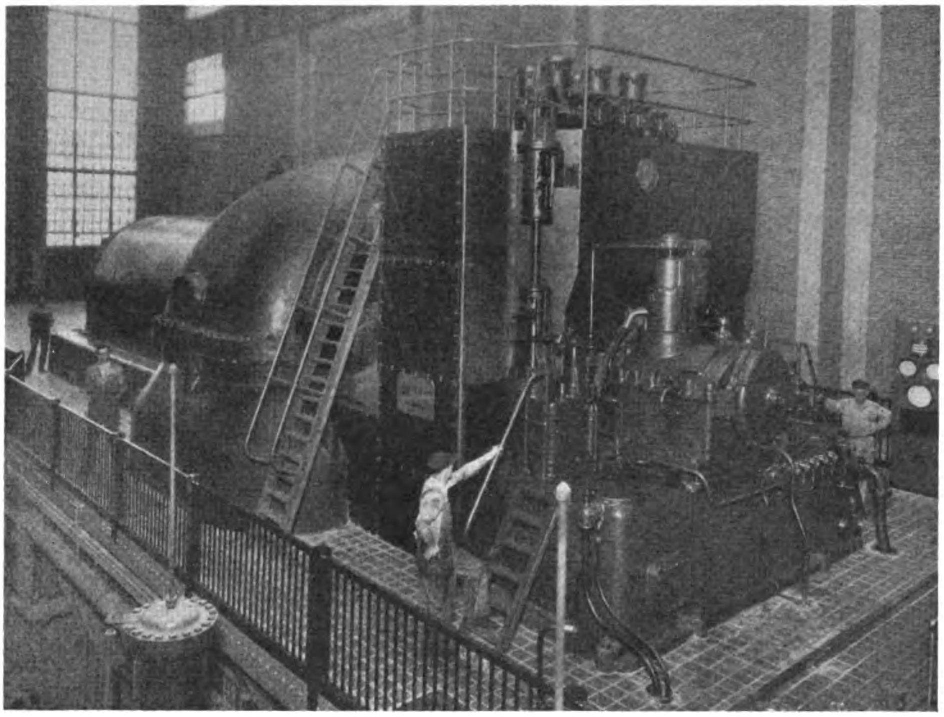


Fig. 6. 75,000-kw. 1800-r.p.m. Single-cylinder Turbine-generator Installed in the Cahokia Station of the Union Electric Light & Power Company, St. Louis (Mo.)

A 75,000-kw. 1800-r.p.m. single-cylinder turbine installed in the Cahokia Station of the Union Electric Light and Power Company (Fig. 6) is the largest single-cylinder 1800-r.p.m. turbine in operation. The generator has a double winding.

A 160,000-kw. tandem-compound turbine-generator (Fig. 7) is now operating in the East River Station of the New York Edison Company. The single center element is a 76,000-kw. high-pressure turbine which exhausts through steam reheaters into two low-pressure turbines, each of which is of double-flow construction and drives a 62,000-kw. main generator and a 4000-kw. service generator. All three turbines operate at 1800 r.p.m., and the main generators are wound for 22,000 volts. Eight vertical condensers are required for the complete turbine.

New Designs

New designs were adopted for turbines of 12,500-kw. capacity at 3600 r.p.m., and for 25,000-kw. and 30,000-kw. capacity at 1800 r.p.m., all arranged for economical operation over a wide range of load. These machines are for moderate pressures only, *i.e.*, up to 400 lb.

A 12,500-kw. 3600-r.p.m. unit of this type for the City of Jamestown (N. Y.) was designed for steam conditions of 275 lb. 200 deg. F. superheat and 1½ in. back pressure.

Two large units of unusual design are under construction for the Super Power Company of Illinois, for installation in the Powerton Station. Each turbine will be of triple tandem-compound construction operating at 1800 r.p.m., and will drive a single generator having a double winding and a capacity of 105,000-kw. Like the two 55,000-kw. machines already in this station, which were the first to have generators wound for 22,000 volts, each of the new generators will also be wound for 22,000 volts. The turbine will operate on steam conditions of 600 lb. 725 deg. F. total temperature, reheat to 750 deg. F., and one inch back pressure. The steam, after leaving the high-pressure turbine, will be reheated in the boiler room to 750 deg. F. before entering the intermediate turbine from which it will exhaust into the double-flow low-pressure turbine.

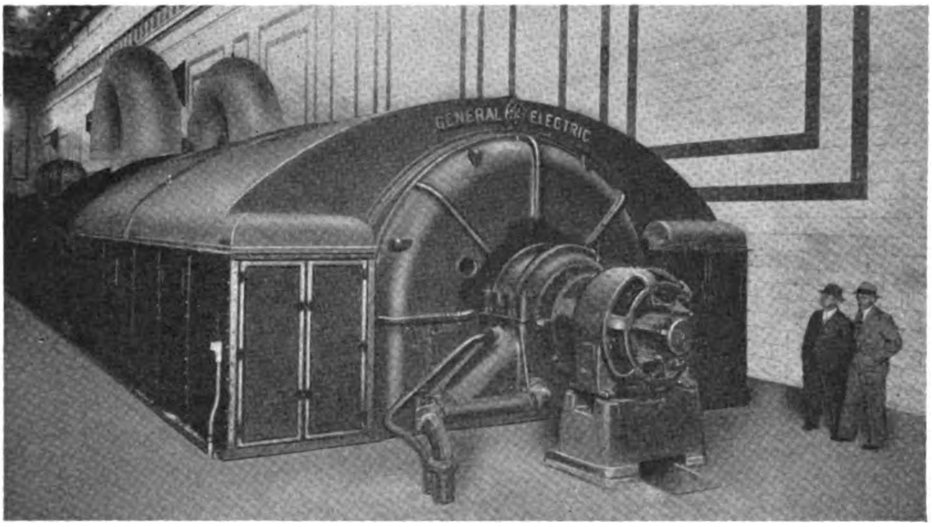


Fig. 7. 160,000-kw. Tandem-compound Generator Operating in the East River Station of the New York Edison Company. The single generator of this unit is the largest of any type ever built

Generators

Two generators employing a double winding were placed in operation: a 160,000-kw. 1500-r.p.m. generator wound for 11,400 volts in the East River Station of the New York Edison Company and a 75,000-kw. 1800-r.p.m. generator wound for 13,800 volts in the Cahokia Station of the Union Electric Light and Power Company at St. Louis. The trend toward larger single generators appears to be quite definite.

INDUSTRIAL-TYPE TURBINES

Higher economies and wider applications were the outstanding results of developmental work on industrial-type turbines. There was a definite demand for higher-speed turbines to meet the high speeds of such driven equipment as compressors (Fig. 8) and for improved economy in the lower-speed range of such equipment as pumps, in which case the new higher-speed turbines were geared to the pumps.

Five turbines were provided with casings of welded steel plates instead of castings. The advantages of the welded construction (Fig. 9) include greater flexibility in laying out the proper number of stages for the energy ranges encountered; more homogeneous material in the casings, and lighter weights.

In some cases, central stations applied turbines to heating plants and to the development of power and steam for industrial customers. An interesting example of this consists of a 6000-kw. unit (Fig. 10) which is operated in parallel with a central-station line and furnishes part of the power and steam at three pressures for an industrial customer. The turbine consists of a non-condensing, automatic-extraction unit from which steam is extracted at two pressures. The pressures in these extraction stages are maintained by internal valves in the machine, regulating the flow to the subsequent stages. The exhaust pressure is maintained by a back-pressure governor; the speed of the unit being held constant by a tie-in with a large 60-cycle system. Provision was made so that if a disturbance occurs on the line connecting the unit with the power system, and the frequency starts to fall off appreciably, the turbine is changed over to speed governing. The pressures at the extraction points are maintained and the excess steam, if any, is exhausted to atmosphere until the fault has been corrected.

A number of industrials having existing boiler plants at pressures from 150 to 200 lb. required increased power without increased steam and, to meet this condition, put in 400 and 600-lb. boiler plants, installing large-flow non-condensing turbine units between these higher pressures and the original equipment.

A large paper mill adopted a cross-compound unit consisting of two 7500-kw. 3600-r.p.m. non-condensing sets operating from 600 lb. to 15 lb. gauge with cross-over pressure in the neighborhood of 200 lb. Steam is bled from both turbines and from the cross-over for feed-water heating and process work.

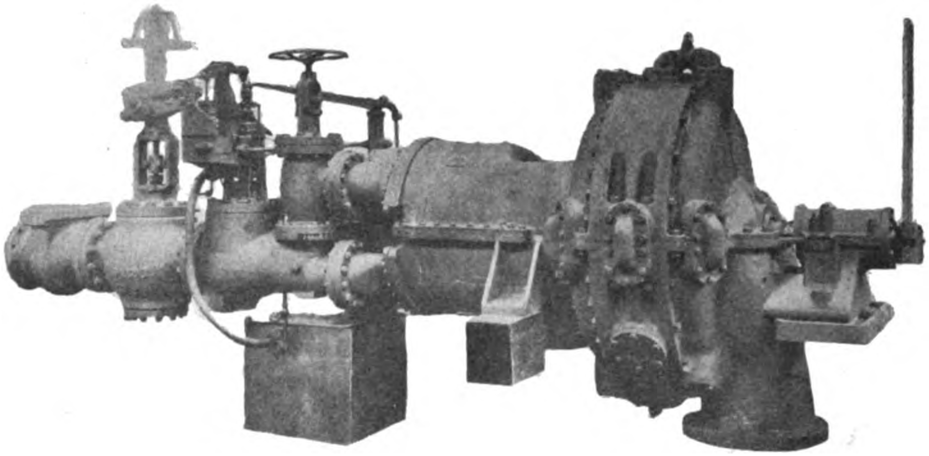


Fig. 8. 1050-hp. Single-stage Non-condensing Turbine Driving 11,100-r.p.m. Centrifugal Gas Booster

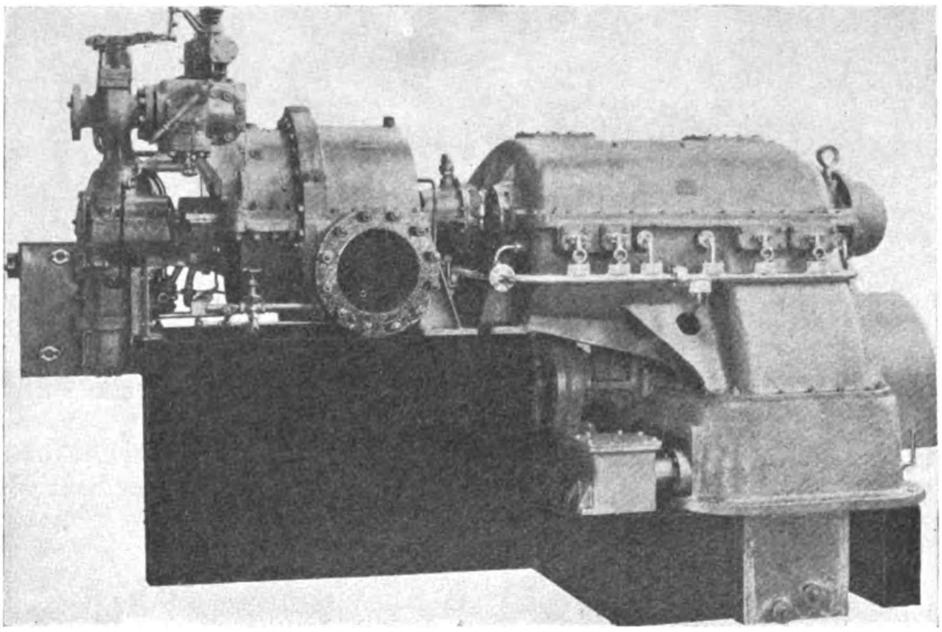


Fig. 9. Double-reduction-geared Turbine with Welded Casing

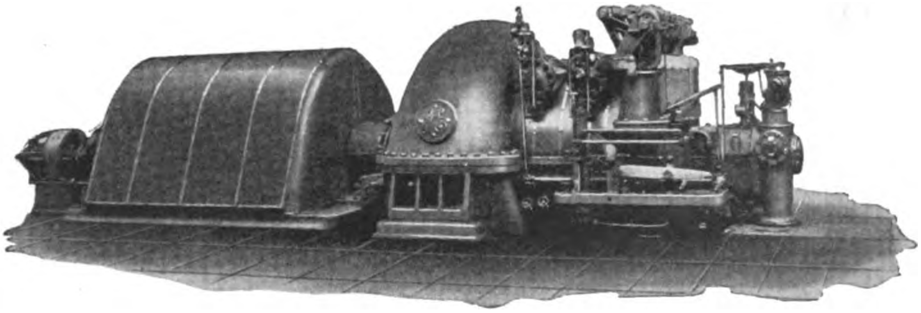


Fig 10. 6000-kw. Non-condensing Automatic-extraction Turbine

EMMET MERCURY-VAPOR PROCESS

The mercury-vapor power-plant equipment installed in the South Meadow Station at Hartford (Conn.) (Fig. 11) was operated during the year for several periods of two to three weeks duration each; inspections of the apparatus being made after each operating period. The first runs, made in October and November, 1928, had shown the advisability of certain modifications in the mercury boiler. Due to the desirability of further research to improve the circulation of mercury within the boiler tubes (Fig. 12), several months were needed to complete these modifications. Subsequent periods of operation proved the boiler to be satisfactory.

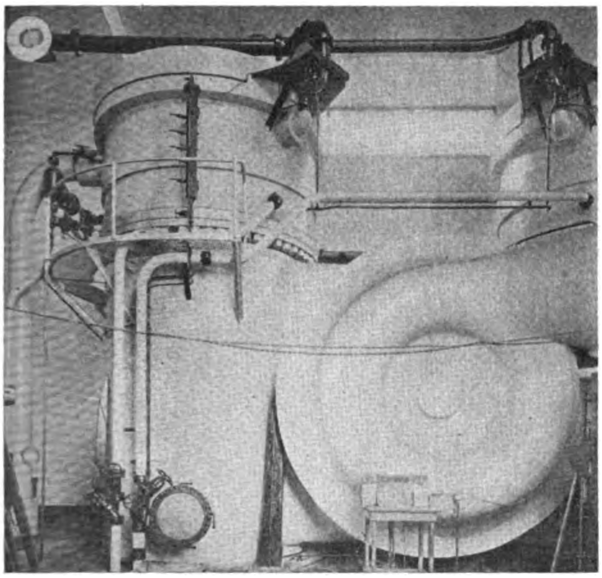


Fig. 11. 10,000-kw. Mercury Turbine and Condensers

A comparison of the results obtained by the unit when running at the highest load which was reached, with the results for which the equipment was designed are as follows:

	As Designed	From Test
Output of mercury turbine	10,000 kw.	10,300
Speed of mercury turbine	720 r.p.m.	720
Steam produced per hour	125,000 lb.	130,000
Steam pressure	350 lb. G.	270
Steam temperature	700 deg. F.	810
Mercury vaporized per hr	1,150,000 lb.	
Temperature mercury vapor	884 deg. F.	880
Pressure vapor at mercury turbine	70 lb. G.	68
Vacuum in mercury condenser	28 in.	28.5
Temperature mercury exhaust	458 deg. F.	
Gas temperature beyond mercury liquid heater	950 deg. F.	1,100
Gas temperature beyond steam superheater	650 deg. F.	720
Gas temperature beyond water economizer	480 deg. F.	
Gas temperature to stack	280 deg. F.	310
Air temperature entering furnace	390 deg. F.	400
Coal burned per hour	14,500 lb.	15,500
Heat in coal per pound	14,500 B.t.u.	14,300

These figures show that the efficiency of the mercury turbine is somewhat better than expected, also that the combustion conditions and heat transfers in the surface beyond the mercury boiler are also better than expected. The reduction of the gas temperature in the mercury boiler was materially less than was intended. This gas temperature has, however, been much reduced by the introduction of certain baffles which prevent by-passing and which force the heated gases to pass through the heating surface of the mercury boiler in a more effective manner than when the test data were taken. This change in baffling the boiler puts more heat into the mercury and thus improves the net economy.

Such steam as was made in this trial, if used in the best large turbine apparatus and with the best methods of regenerative feed heating, would produce 14,000 kw. plus all necessary auxiliary power. There would thus be obtained 24,300 kw. from a consumption of 15,500 lb. of 14,300-B.t.u. coal per hour, or 9140 B.t.u. per kw-hr.

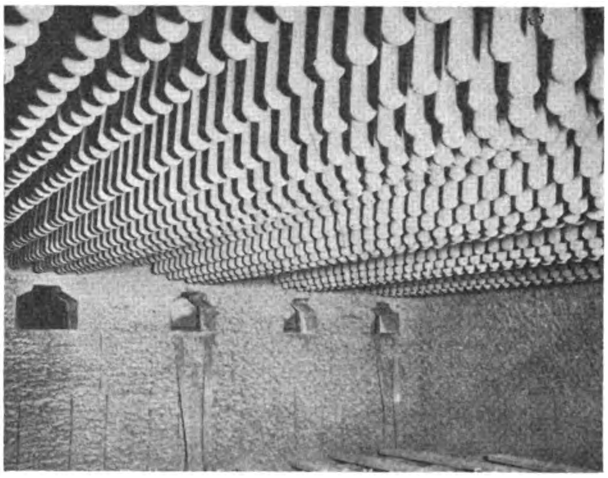


Fig. 12. Mercury Boiler Tubes and Furnace Walls
After 100 Hours' Run

This equipment, while operating, makes a saving at Hartford of about $800 per day in fuel alone.

Six mercury-boiler units were installed in an oil refinery; the mercury vapor generated by them being used for refining oil. The highest mercury pressure used is 200 lb. gauge, corresponding to a vapor temperature of more than 1000 deg. F. Some of these boilers have been in service for several years and have been in operation or ready for operation 98 per cent of the time.

MARINE EQUIPMENT

There was exceptional activity in the production of turbine-electric propelling equipment for the merchant marine service, and at the close of the year there had been completed, or were under construction, equipments of this type for six ships aggregating more than 56,000 gross tons, utilizing alternating-current propelling motors totaling more than 71,000-s.hp. capacity.

Electric propulsion was, for the first time, applied to railroad car ferries, large pleasure yachts, and as auxiliary equipment for increasing the power on reciprocating-engine-driven ships.

Turbine Electric

The commissioning of the S. S. *Pennsylvania* (Fig. 13), the third turbine-electric passenger liner for operation on the Panama-Pacific Line of the International Mercantile Marine Company, marked a distinct epoch in our maritime history, for this ship, together with the S. S. *California* and S. S. *Virginia*, rounded out the largest single fleet of all-electric craft, from the standpoint of tonnage, in commercial service. These three ships are also the largest of their type so far built in American shipyards.

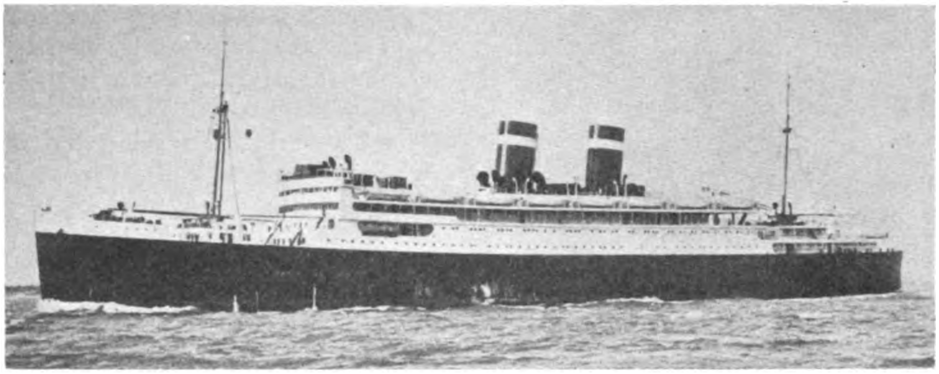


Fig. 13. S. S. *Pennsylvania*, the Third Electric Passenger Ship of the International Mercantile Marine Company

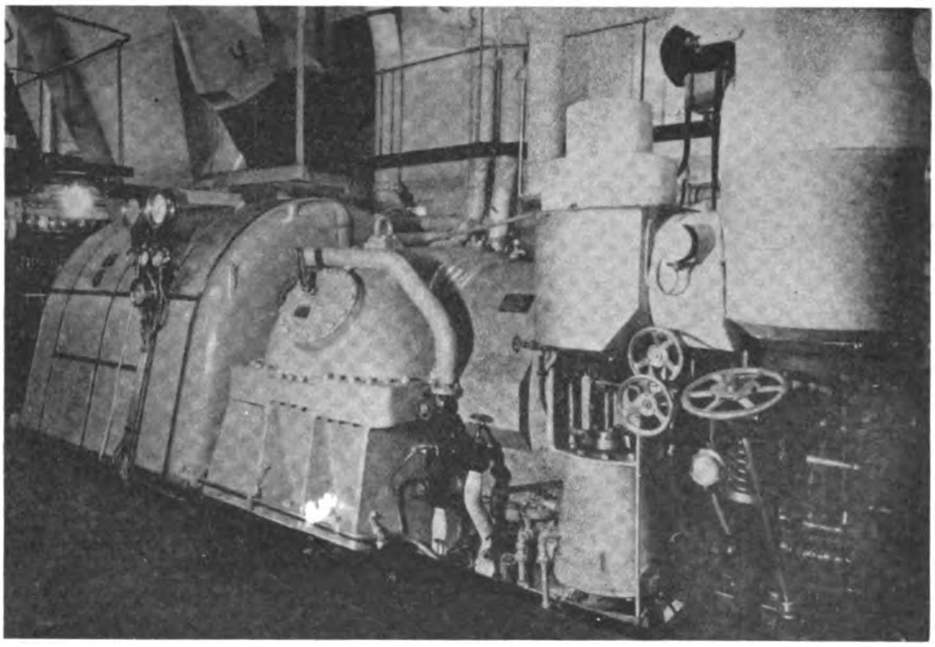


Fig. 14. One of the Two 6600-kw. Steam-turbine Generators Installed on S. S. *Pennsylvania*

The power-plant installation for the S. S. *Pennsylvania* comprises two 6600-kw. 2880-r.p.m. alternating-current turbine-generators (Fig. 14), utilizing 270-lb. steam at the throttle, with a total temperature of 614 deg. F., operating with a 28½-in. vacuum. The twin screws are driven at 120 r.p.m. by two 8500-hp. 4000-volt alternating-current motors (Fig. 15), which are direct-connected to the propeller shafts.

Construction of the S.S. *Santa Clara* for the Grace Line was nearing completion, the electric equipment consisting of two 4850-kw. 2950-r.p.m. turbine-generators, and two 6300-s.hp. 3000-volt alternating-current motors for operating the propellers at 118 r.p.m. It is expected that this ship will be placed in commercial service early this year.

Two ships designed for service on the New York-Havana Trade Route for the Ward Line will each be equipped with two 6100-kw. 3168-r.p.m. turbine-generators supplying energy to the two (Fig. 16) 8000-hp. 3150-volt 144-r.p.m. alternating-current propeller motors.

Toward the close of the year, the Dollar Line, which operates ships in a round-the-world service, decided to adopt turbine-electric drive for two ships, which in point of size and power will surpass any of their class heretofore constructed in the United States.

The electric equipment for the first of the two turbine-electric car ferries under construction for the Pere Marquette Railway was completed. The two turbines for each ship are each rated 3380 kw., at 3600 r.p.m., and will utilize steam at 300 lb. pressure, 200 deg. F. total temperature, and 28½ in. vacuum. The propeller motors are of the slip-ring induction type, each rated 3600 hp., 2300 volts, at 120 r.p.m.

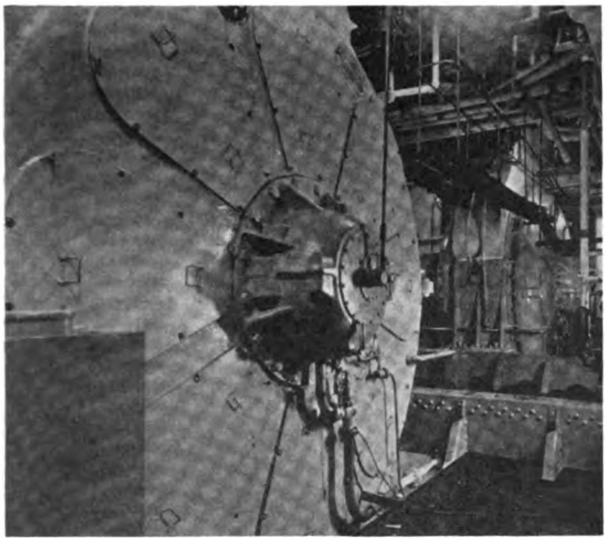


Fig. 15. Two 8500-hp. 4000-volt Alternating-current Motors Driving the Twin Screws of the S. S. *Pennsylvania*

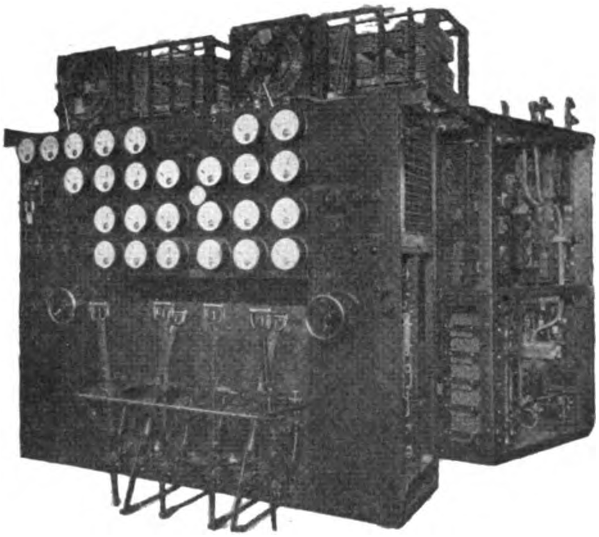


Fig. 17. Control Equipment for Pere Marquette Railway Turbine-electric Car Ferry

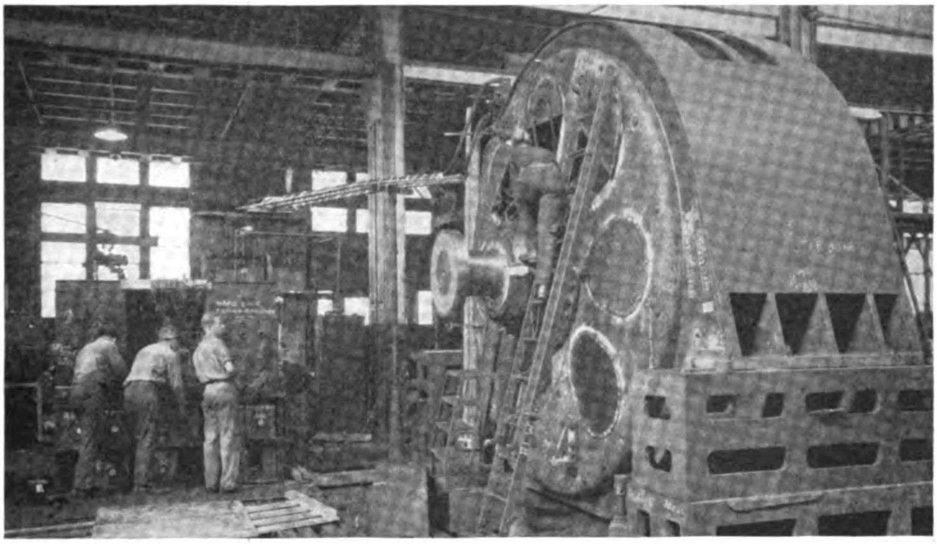


Fig. 16. 8000-hp. 3150-volt Alternating-current Propeller Motor for Ward Line Ship Being Tested in Factory

As these car ferries operate on the Great Lakes at all seasons of the year, special features have been incorporated in the control equipment (Fig. 17) to insure safety when the ship encounters ice. Under these conditions, before an injurious overload can be imposed on the propeller motors, the power input to them is automatically reduced and then automatically built up, and the ship will accelerate to the full speed of 22 miles per hour without the necessity for manipulation of the control equipment.

The 16-knot twin-screw yacht, *Viking* (Fig. 18), was the first ship of this type to be provided with turbine-electric propulsion. The two turbine generators are each rated 1230 kw. at 3600 r.p.m., and the driving motors, 1300 hp., 1150 volts, at 160 r.p.m.

A larger yacht, for which similar equipment is being constructed, will utilize two 2680-kw. 3600-r.p.m. turbine-generators, and two 3000-hp. 257-r.p.m. motors.

An interesting application of turbine-electric equipment to supply power supplementary to existing reciprocating-type marine engines was adopted for six twin-screw European ships. These equipments (Fig. 19) consist of exhaust turbines driving alternating-current generators which supply power to induction motors mounted on the same propeller shafts as the reciprocating engines. In this way, the economy of the power plant is increased so that, with the same boiler capacity, it has been possible to get approximately 25 per cent more power.

A direct-current generator for supplying auxiliary power and excitation for the main generator is also driven by the exhaust turbine, and live steam is admitted to the turbine when its exhaust connection is broken during maneuvering periods; during which time the reciprocating engines only are used. The turbine is in this way kept running so as to insure a continuous supply of direct current. By this simple method of exhausting from reciprocating engines through a turbine, it is possible to secure a considerable increase in speed in reciprocating engine-driven ships with a minimum of outlay for the increased power plant.

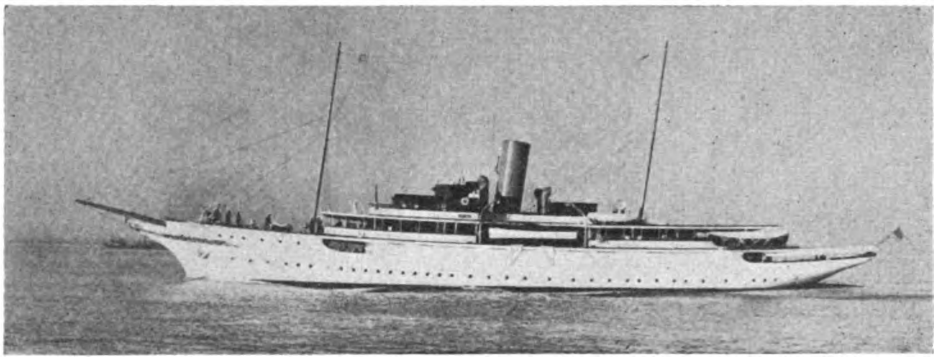


Fig. 18. The *Viking*, First Turbine-electric Yacht

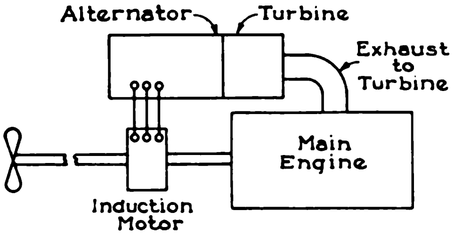


Fig. 19. Diagram Showing the Relative Arrangement of Reciprocating Engine, Turbine-generator, and Propeller Motor

AVIATION

Radio Altimeter

The hazards incidental to blind flying in fog are being greatly reduced by the development of a method of depth sounding in the air to enable aviators to determine their height with reference to the surface over which they are flying. This is accomplished by sending out radio impulses from the aircraft, which are reflected back from the surface of the earth. The frequency of these impulses changes cyclically with changes in the height above the earth and suitable instruments permit a conversion of these changes into height readings. In addition to giving scale indications, the instrument warns the aviator by distinctive signals when approaching the earth.

Magneto Compass

This compass is made up essentially of a generating unit, a remote-indicating instrument, and a course-setting mechanism. The generating unit (Fig. 20) is mounted in some part of the aircraft relatively free from disturbing magnetic influences, such as "aft" in the fuselage near the tail assembly. It is located inside the fuselage with the drive shaft extending outside so that the wind-driven rotor is turned by the air in flight, thus driving the generator. The remote-indicating instrument, course-setting controller, and sensitivity controller (Fig. 21) may be located convenient to the pilot irrespective of proximity to local magnetic disturbances, and all are customarily installed on the ship's instrument board. The indicator is connected with the generator by simple twin-conductor cable, and the rotating motion of the course-setting controller is transmitted through a flexible shaft to a worm-gear assembly on the

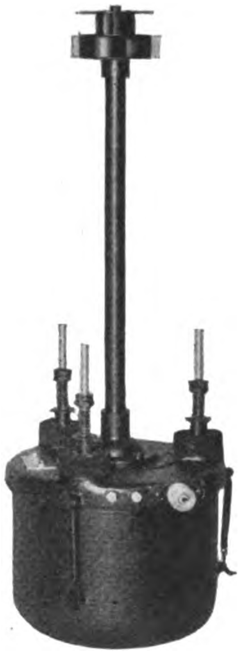


Fig. 20. Magneto Compass Generating Unit

generator. The sensitivity controller is a variable shunt across the indicator.

The net weight of the generating unit, complete with enclosing bowl, wind-driven rotor, and mounting fittings is 5 lb. and 10 oz. The indicator, controllers, and usual lengths of wiring and flexible shafting add approximately 6 lb.

The compass operates as a direct-current generator having an armature and commutator (Fig. 22) but using the horizontal component of the earth's field as its field. Pole pieces are provided to concentrate the lines of force of the earth's field and produce a stronger field in which to operate. Since the machine is bipolar (one North pole and one South pole) only a single pair of pole pieces is required. When the pole pieces lie parallel to the direction of the horizontal component of the earth's field (*i.e.*, magnetic North and South) the generator field strength is at its maximum thereby causing a maximum generated voltage, and when the pole pieces are at right angles to the direction of the earth's field (*i.e.*, magnetic East and West) the generated voltage is zero.

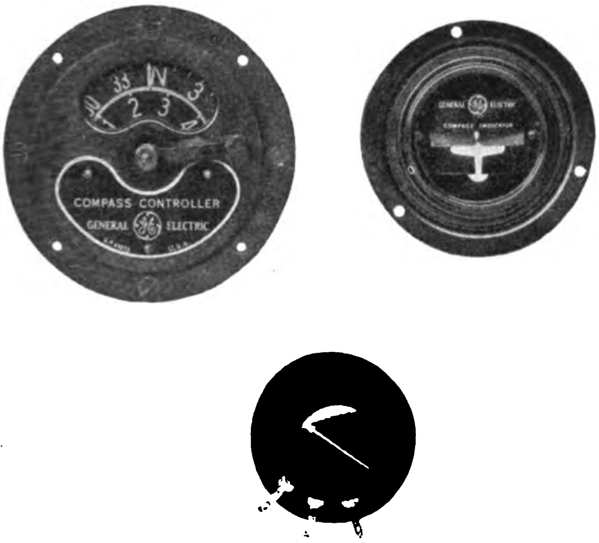


Fig. 21. Indicator, Course-setting Controller, and Sensitivity Controller for Magneto Compass

A reversal of the pole pieces changes the polarity of the generated voltage. Thus, with the pole pieces pointing East and West, the indicating instrument hand (Fig. 21) is on zero in the center of the scale on the nose of the miniature airplane which is stationary. A swing of the pole pieces from the East-West position picks up some of the earth's field and causes the generator to generate positive for one direction and negative for the other. The corresponding indication on the instrument shows that the aircraft has turned to the right or left of the predetermined course.

By means of the course-setting mechanism, the pole pieces are so set with respect to the line of flight of the aircraft that when the ship is flying on the desired course the pole pieces lie East and West. Any deviation from this course swings the pole pieces out of the East-West position and causes the generator and indicator to function, showing the pilot that he must turn to the left or right as the case may be to get back on his course. In flying due magnetic North or South the pole pieces are at right angles to the longitudinal axis of the aircraft, and in East or West flight they are parallel to it.

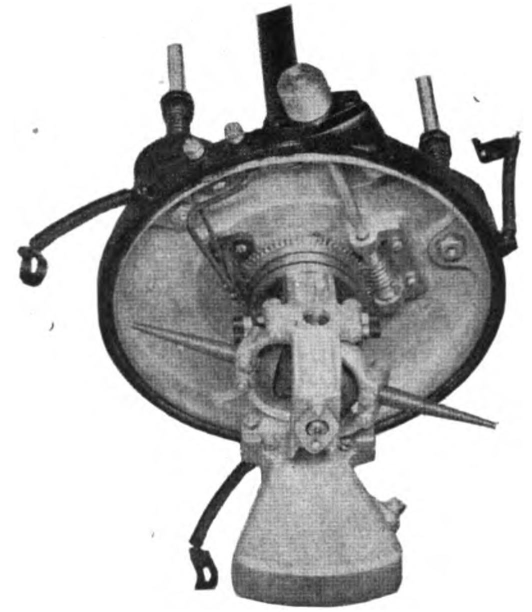


Fig. 22. Magneto Compass Mechanism, Showing Worm and Gear for Course-setting Control

Electric Gasoline Gauge

This gauge (Fig. 23) depends for its operation on the hydrostatic head (pressure) of the gasoline to be measured and has no moving parts whatever except for the needle of the indicating instrument and the switch. Its principle of operation insures accurate readings under practically every condition of normal flight.

Essentially it is an electrically-operated remote-indicating pressure balance—the electric energy being supplied by the storage battery, dry-cell battery, or electric generator with which the aircraft is equipped. A complete installation consists of one or more pressure-balance units, a remote-indicating instrument (actually a milliammeter calibrated in gallons) having as many scales as there are separate tanks to be measured, and a normally open hand-operated tumbler switch for each pressure balance. Every tank to be measured independently of the remainder of

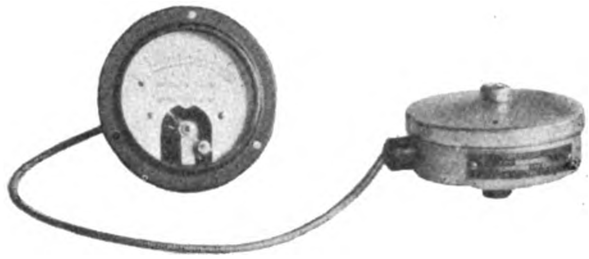


Fig. 23. Gasoline Gauge Showing Pressure Unit and Instrument-board Indicator for Aircraft

the gasoline supply requires a separate pressure balance, but where it is only necessary to measure the total contents of a multi-tank ship one pressure balance alone will serve the purpose.

The normally-open tumbler switch insures a dead circuit at all times except when the pilot wishes to read his gasoline supply. Electric remote indication permits the simplest possible connections between pressure balances and indicating instruments, even though the balances may be located in the most inaccessible parts of the aircraft. An ordinary one-unit installation weighs approximately 3 lb. complete.

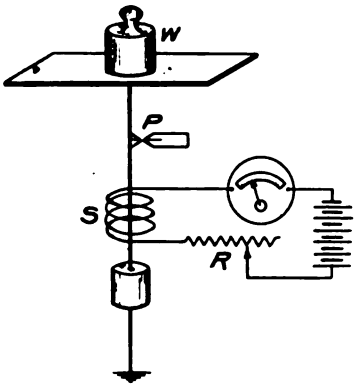


Fig. 24. Diagram Illustrating Principles on which Aircraft Pressure Gauge Operates

The principle of operation is briefly as follows: the downward force of the weight W (Fig. 24) is balanced against the upward pull of the solenoid S. By means of a variable resistance R the current through the solenoid S can be increased until it is just sufficient to lift the weight. By observing the pointer P, this current can be quite accurately determined and its value will be indicated on the ammeter shown. In other words, the ammeter of this device can be calibrated to read "pounds" on the platform instead of "amperes." Such an apparatus would be accurate, but would not be of much value because one would have to watch the pointer and at the same time adjust the rheostat.

The balance scheme actually used is automatic. The weight, the solenoid, the ammeter, and the battery are all identical, but the resistance is placed under the weight and in such a manner that it is automatically operated by the force applied to the platform. The resistance is a stack of small carbon rings which changes its resistance as pressure is applied. When a weight is placed on the platform its first action is to compress the carbon disks. This causes an increase of current through the solenoid, which relieves the pressure on the carbon pile. Equilibrium is reached when the current through the solenoid is just sufficient to balance the weight.

Only a small percentage of the total weight is required to operate the carbon pile, and this is so small that even large differences in the pressure-resistance characteristic have very little effect on the accuracy of the device. In practice, 95 per cent of the weight is balanced by the solenoid. Five per cent is required to compress the carbon pile. Assuming a change of 10 per cent in the pressure-resistance characteristic of the pile, the change in overall accuracy would be only 10 per cent of 5 per cent, or ½ of 1 per cent.

Engine-temperature Indicator

Engine-temperature indicators of the thermometer type, as commonly used in aircraft, indicate lubricating-oil or cooling-water temperatures rather than the temperatures of the engines themselves. In the case of air-cooled engines, it is customary to locate thermometers in the lubricating-oil lines, or in water-cooled engines in the cooling-water systems. Whereas both of these applications give indications of the general thermal condition of the engines, it is also important for long engine life and dependable operation to know at all times the rate at which engines are heating or cooling as well as the temperature of vital hot spots. This is especially true of air-cooled engines, where too rapid heating may be detrimental and where very fast cooling may occur without visual warning to the pilot—for instance, during a long glide in cold weather preparatory to landing. Under such conditions engines may become so cold as to fail to function if power is suddenly needed.

The thermocouple engine-temperature indicator (Fig. 25) accurately measures the temperature of cylinder heads, cylinder walls, or any hot spots that may be of particular significance. It is instantaneous in operation and, therefore, gives immediate indications of heating and cooling. A complete indicator consists of a thermocouple, twin-conductor leads, and a cold-junction temperature-compensated remote-indicating instrument.

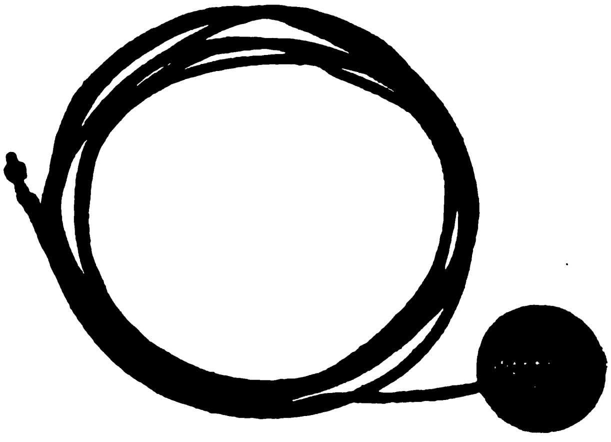


Fig. 25. Thermocouple Aircraft Engine Temperature Indicator

In the laboratory and test room, thermocouples have been used for this purpose for some time, but they have been limited in aircraft applications by the necessity of the operator having to correct for varying air temperatures. This objection, however, has now been overcome as all corrections are automatically made by the instrument by means of a special metal in which magnetic permeability changes with changes in temperature. No battery or electric energy supply of any kind is required, as the thermocouple generates its own electricity in proportion to the temperature to which it is heated.

The indicator is accurate to within 3 deg. F. for ordinary air temperature changes. Where extreme variations are encountered, such as between sea level and high altitudes, the maximum error is not more than 10 deg. F. Since it is customary to calibrate the scales from 100 to 650 deg. F. for air-cooled engines, the maximum error of 10 deg. is relatively small. The total weight is 1 lb. 3 oz.

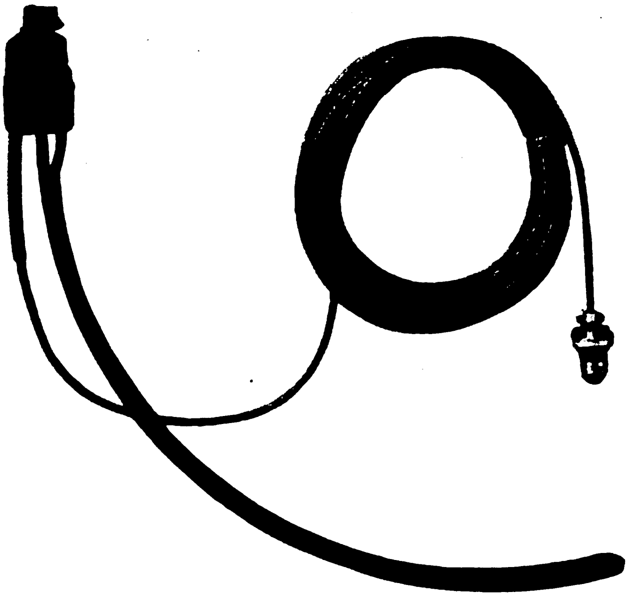


Fig. 26. Electric Oil-immersion Heater for Aircraft Engines

Oil Immersion Heater

Heating the oil supply in cold aircraft engines requires considerably more time than "warming up" the engines themselves, as there is a relatively large amount of oil to be heated and only a small part of it is brought in contact with the engines at any one time. If the oil heating is dependent on engine heat alone, it is necessary to wait until the entire supply of oil is pumped through the engines a sufficient number of times to raise its temperature to the required point. This may be a matter of ten minutes or a half hour. In cases of extremely cold weather it is usually imperative to preheat the oil before even starting the engines.

Aircraft oil-immersion heaters (Fig. 26) were designed to "warm up" lubricating oil without the aid of the engines and without the necessity of draining and refilling in cold weather. It is intended to use these heaters as part of the ground equipment rather than to install them permanently in aircraft. They are portable, and so shaped as to permit easy insertion through the oil tank filler caps.

The sheath-wire heating elements consist of coiled nickel-chromium resistors imbedded in highly compressed magnesium oxide, all encased in metal sheaths which separate the resistors from the liquid and also protect them from mechanical injury. Steel is used for the sheaths since it is best suited to withstand the action of oil. By designing the heating elements so that heating occurs only over the submerged portions, the possibility of burning the surface of the oil is avoided.

ELECTRIC RAILWAYS

In the electric railway field, operation of both street cars and buses in city streets was improved by faster acceleration and braking. Faster acceleration is being secured by the use of a platform type of electro-pneumatic control, which allows the controller to speed up automatically at a much faster rate than the older designs, without discomfort to the passengers, and faster braking is accomplished by the use of quick application and release valves for the air brakes and by the use of magnetic track brakes.

The new type edgewise-wound resistor, brought out in 1928, has been widely adopted on account of its light weight and durable construction.

An improved gear construction, known as the non-resonant type, effects an appreciable reduction in the amount of gear noise.

A notable installation, incorporating all of the recent improvements in design, is a car (Fig. 27) now in service on the lines of the United Traction Company in Albany. It weighs 32,500 lb. and is equipped with four 35-hp. motors, foot-operated electro-pneumatic control (Fig. 28), foot-operated air brakes, and magnetic track brakes. The demonstration has been impressive and many of these features have already been adopted by other companies. The Chicago surface lines, for example, placed in service during the year one hundred cars with the new type of control. A number of these cars are also using a newly designed 40-hp. light-weight motor and a center-gear air compressor.

Trolley Buses

Unusual interest was displayed in the possibilities of trolley bus application on city lines. Fifteen such equipments were placed in service in Salt Lake City (Utah); each equipped with two 50-hp. motors, electro-pneumatic control, and dynamic braking. Four similar buses, but without the braking equipment, were provided for the city lines of Knoxville (Tenn.), and one demonstration equipment was operated in New Orleans (La.).

Rapid-transit Lines

Some activity was shown in new equipment for the operation of rapid-transit lines. Perhaps the most extensive work is being done by the city of New York in the construction of a new subway in the Bronx, for which equipment is now under construction. There was also some activity in this line in foreign fields including South America, Japan, and Australia.

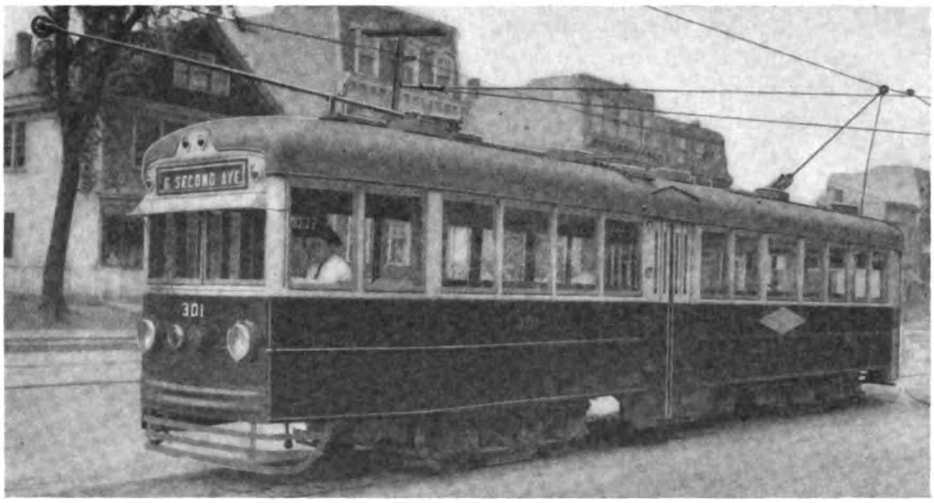


Fig. 27. Light-weight Car with Electro-pneumatic Control; United Traction Company, Albany (N. Y.)

Steam-road Electrification

Several outstanding railroad electrification projects were definitely initiated during the year; probably the most important being that of the New York Central Railroad Company in connection with the recently concluded plans for the reconstruction of the "West Side" railroad tracks in New York City.

The plans adopted provide for the complete elimination of steam from the entire district from Spuyten Duyvil south. Forty-two six-motor locomotives are now under construction which will be utilized to handle freight from Croton, the present northern terminus of the electric zone, south to the Sixtieth Street yards. Provision will be made for operating from either third rail or overhead catenary line. South of this point all freight service will be handled by oil-electric storage-battery locomotives.

The electrification project of the Delaware, Lackawanna and Western Railroad involves the construction of 141 motor and control equipments to be used on 3000-volt direct-current multiple-unit cars. The motor-car trains (Fig. 29) will be made up of reversible units, each consisting of a four-motor single-end driving unit and a trail car with a master controller for operating the unit. Trains will thus be made up of an equal number of motor cars and trailers, each of the two-unit sections being reversible. This will be the first extensive installation of 3000-volt direct-current motor car equipment. The power supply arrangements for this project are unique in that the energy will be supplied entirely through mercury-arc power rectifiers.

Reports of the electrical operation of the new Cascade Tunnel of the Great Northern Railway and adjacent sections indicate an appreciable improvement in revenue passenger service, which has justified the addition of new trains and motive power. Four additional motor-generator type locomotives, duplicates of those now handling the passenger service on this division (Fig. 30), are under construction to take care of expected requirements for passenger-train service in the electric zone. These locomotives, previously referred to as being the largest single-unit motor-generator locomotives ever built, have made an

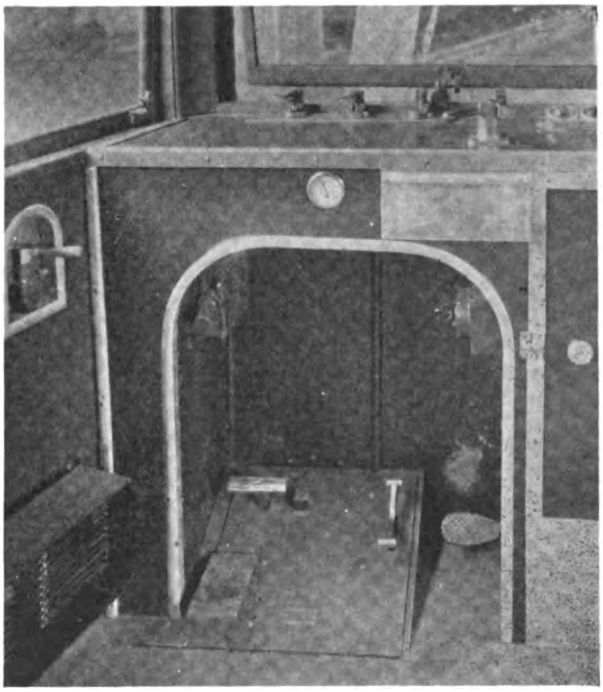


Fig. 28. Arrangement of Foot Control and Auxiliary Control Handles in Light-weight Car

enviable record in service and seem eminently suited to handle the passenger service over this line. If desired, they can also handle without difficulty heavy freight trains at lower speed and can be operated as double-unit locomotives.

The Paulista Railway in Brazil, which is now operating all of its wide-gauge lines electrically, added five passenger locomotives, weighing 150 tons each, in 1928. During 1929, four similar locomotives (Fig. 31), but designed for freight speeds, were completed and placed in service, making a total of thirty G-E locomotives for freight, passenger, and switching work now in service on this railway. The freight locomotives are of the single box-cab type, carried on two three-axle articulated driving trucks with a single-axle guiding truck at each end.

Work on the electrification of the Cleveland Union Terminal Lines proceeded rapidly and eighteen of the twenty-two 204-ton locomotives (Fig. 32) intended for this service were completed. The construction of the remaining units will be completed early in 1930. Exhaustive tests indicate that these locomotives will easily meet all requirements.

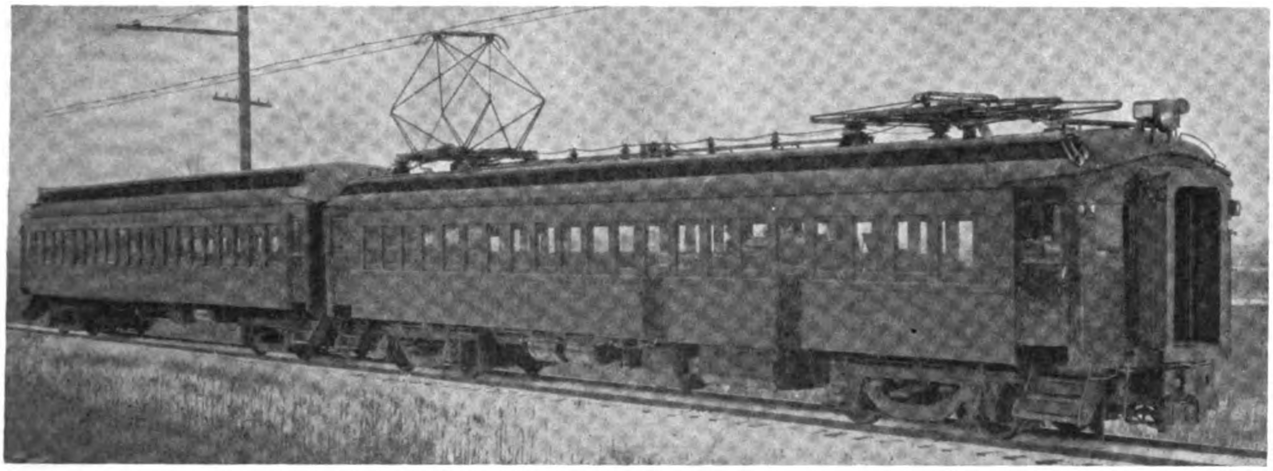


Fig. 29. 3000-volt Direct-connected Motor Car and Trailer; Delaware, Lackawanna & Western Railroad

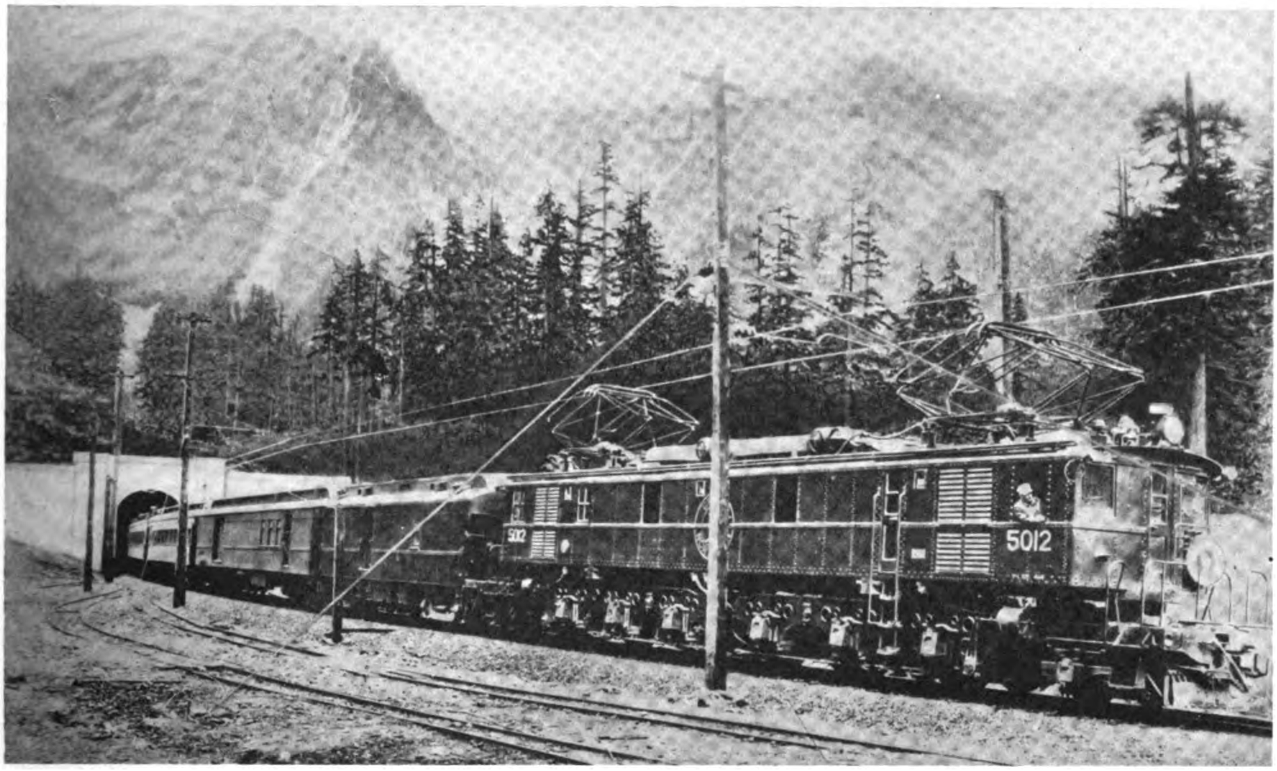


Fig. 30. Motor-generator Type Locomotive Hauling the Great Northern Railway Train "The Empire Builder"

Two new single-phase passenger locomotive equipments for the Pennsylvania Railroad were being built in accordance with specifications prepared by the railroad company. They each consist of a 2-B-2 running gear with flexible-geared motors for each driving axle.

Operating Data

Unusually complete operating information was secured demonstrating the economy of electric operation on the Mexican Railway, which is now using twelve 150-ton 3000-hp. locomotives.

Operating data for a period of six months was also published, covering the multiple unit service of the recently electrified Boston, Revere Beach and Lynn Railroad. Not only have the operating costs on this line been reduced, but an actual increase in revenue passenger traffic has been secured.

Oil-electric Locomotives

For handling all freight service below the Sixtieth Street yards the New York Central Railroad Company will use the oil-electric storage-battery type of locomotive, similar to the trial unit which has been in service on this line for more than a year. Thirty-five

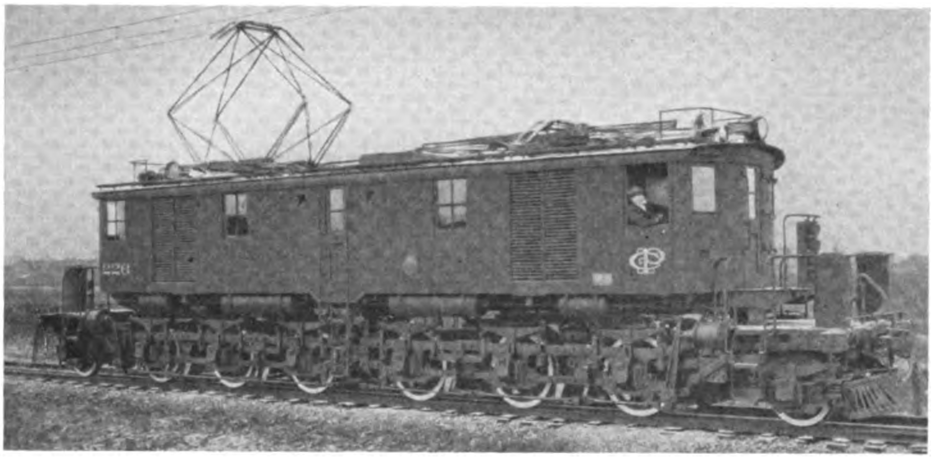


Fig. 31. 150-ton 3000-volt Locomotive for Freight Service on the Paulista Railway (Brazil)

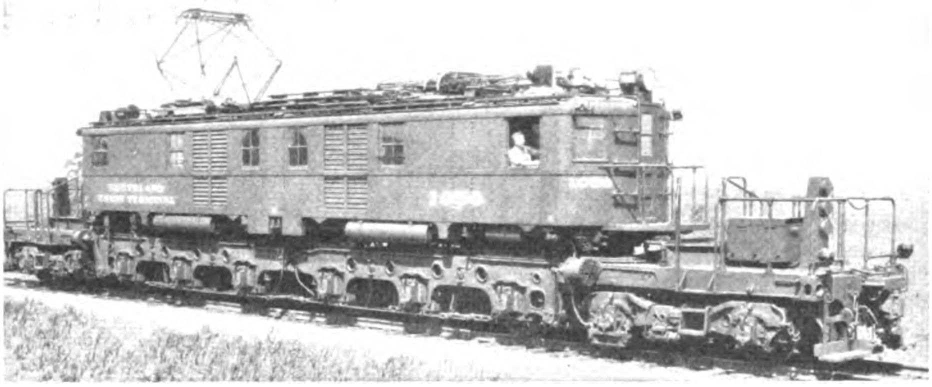


Fig. 32. 204-ton 3000-volt Railway Locomotives for Cleveland Union Terminals Co.

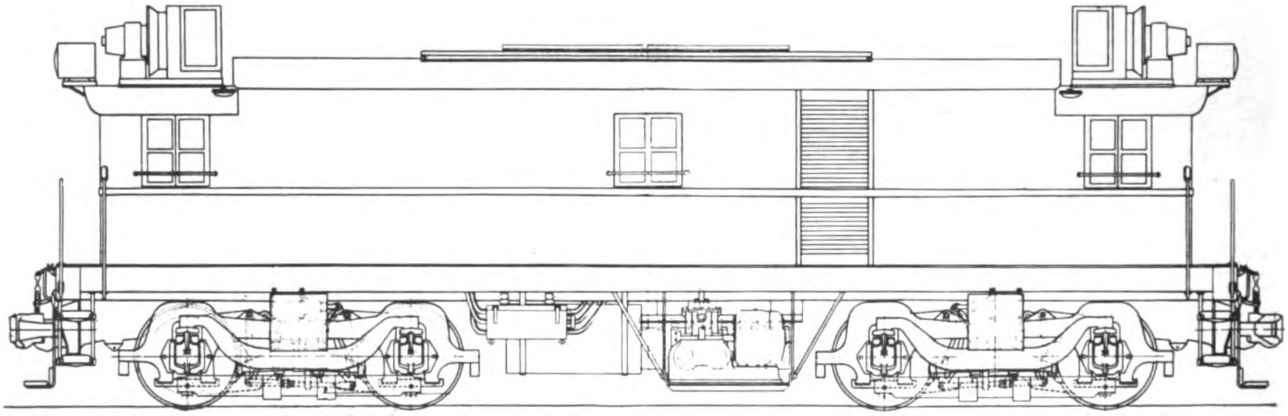


Fig. 33. Outline of Oil-electric Storage-battery Type Locomotive for New York Central Railroad

such units, popularly known as the three-power locomotive (Fig. 33), are now under construction, each of which will weigh about 128 tons. The equipment is arranged to operate either from a storage battery or the oil engine, or a combination of the two, and may also be operated from the third rail or overhead trolley when in the electric zone. The unusual versatility of this type of motive power makes it particularly suited to operation on switching tracks, unloading and loading car floats, and for entering warehouses and other buildings. The 300-hp. oil engine used has been found ample for maintaining the storage battery in a well-charged condition and the short time tractive effort which can be obtained from the engine and battery combined is sufficient for handling any duty required in this zone.

A somewhat different type of oil-electric battery locomotive is being operated in the yards of the Illinois Central Railroad. This locomotive was built by the St. Louis Car Company and is equipped with two 155-hp. Buda engines, driving 400-volt generators. The engines are designed to use furnace oil for fuel. The locomotive can be operated from either a 750 or 1500-volt trolley or from a 108-cell battery. A similar unit is under construction for the Illinois Terminal Railway to be used in the switching yards at St. Louis.

An unusual type of storage battery oil-electric locomotive is being built for the Delaware, Lackawanna and Western Railroad. Two of the locomotives are under construction and they will be equipped to receive power from a 3000-volt d-c. trolley when operating in the electric zone. When operating in portions of the switching yards not supplied with an overhead distribution they will take power from a 300-hp. Ingersoll-Rand oil engine and the storage battery. This equipment will be similar to that used on the New York Central three-power locomotives except that provision is made for operating from a 3000-volt trolley.

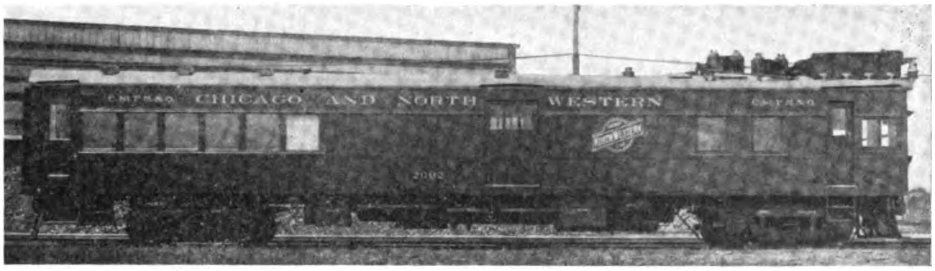


Fig. 34. 600-hp. Gas-electric Passenger and Express Motor Car; Chicago & Northwestern Railroad

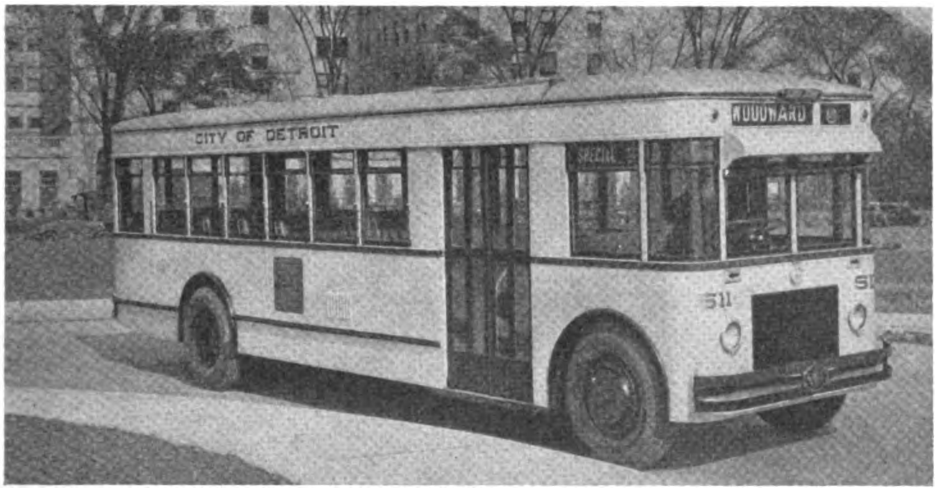


Fig. 35. 40-passenger Metropolitan Gas-electric Bus for the City of Detroit

Additional oil-electric locomotives were also completed as follows:

- Five 110-ton for the Illinois Central Railroad Company.
- One 110-ton and one 70-ton for the Hoboken Terminals Company.
- One 110-ton and one 70-ton for the Ford Motor Company.
- One 110-ton for Foley Brothers.
- Three 70-ton for the Donner Steel Company.
- Two 37-ton for the Chiriqui Land Company.

Gas-electric Cars

The number of steam railroads which have taken advantage of the gas-electric car for the economical handling of branch-line passenger work (Fig. 34) steadily increased and many roads already using this equipment have consistently added to the number of cars in service. On a number of roads distillate fuel is being successfully used in place of gasoline. Engines suited to this duty, using fuel oil, are being developed.

The general tendency indicates a continued increase in size and in the capacity of the horse power installed. A number of cars in service are using two 400-hp. engines and quite a large percentage of those now under construction or recently placed in service are provided with 400-hp. engines. On some of the heavier cars a 525-hp. unit is used. Among the more prominent users of gas-electric cars are the following:

Road	No. Placed in Service 1929	Total Gas-Electric Cars
Chicago, Burlington & Quincy Railroad	2	45
Chicago, Rock Island & Pacific Railroad	9	34
Great Northern Railway	6	24
Atchison, Topeka & Santa Fe Railroad	19	22
Chicago Northwestern Railway	14	37
Southern Pacific Company	13	16

Ten cars equipped with 220-hp. gas-electric units were delivered to the Victorian Railways in Australia.

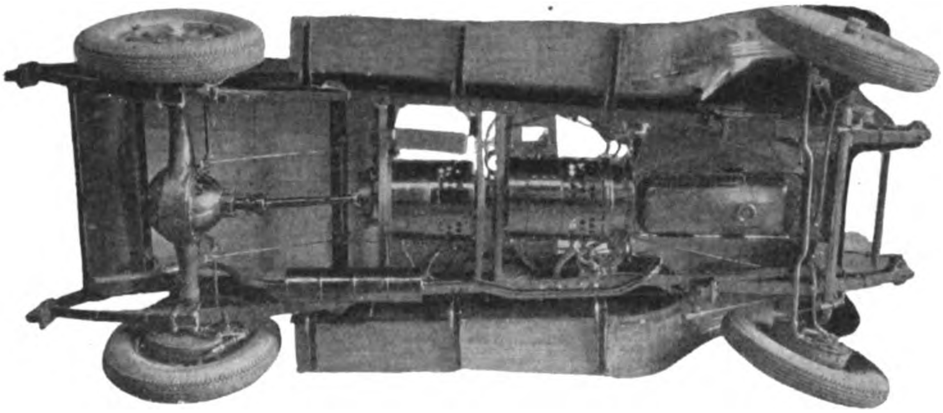


Fig. 36. Stearns-Knight Chassis Showing Arrangement of Gas-electric Driving Equipment

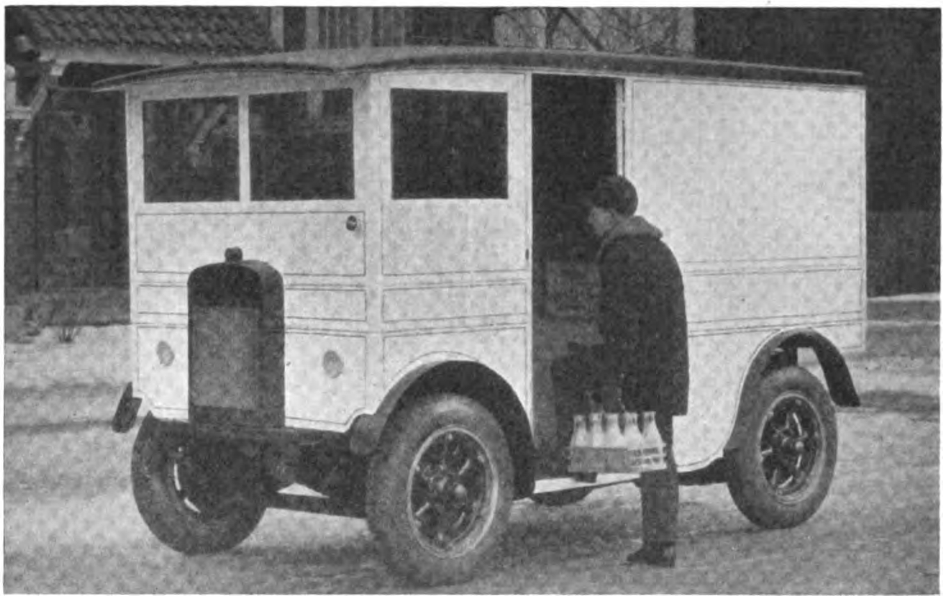


Fig. 37. A Thorne Gas-electric Delivery Truck Utilized in Door-to-door Service

Gas-electric Buses

In general, the trend is to much larger buses, making electric drive more essential as it is far superior in operation to mechanical drive under these conditions. The demand for this type of equipment continued for large city fleets and it was also utilized for a number of novel applications.

Five pleasure cars of this type (Fig. 36) were so equipped, using a Stearns-Knight model 6-80 engine and chassis. Owing to the smooth acceleration and easy handling which is secured with electric drive, it is probable that the application to this type of car will increase as the development becomes standardized.

Another service in which electric drive offers many advantages is the so-called door-to-door delivery truck (Fig. 37), which is being manufactured by the Thorne Motors Corporation, Chicago. One hundred of these trucks were placed in service and twenty-seven more are under construction.

An unusual application of electric drive was made by the U. S. Signal Corps. It comprises three portable power-plant units each consisting of a one and one-half ton truck with a paneled body containing a motor-generator set and switchboard for supplying 12-volt and 2000-volt current for radio transmission. Two of these trucks are used for supplying the current to the transmitter and a third for battery charging.

The principal installation of the year of gas-electric bus equipment was made by the Public Service Company of New Jersey, which added 161 units to its fleet. The Philadelphia Rapid Transit Company added twelve, and the Detroit Street Railways twenty-five. Three buses with gas-electric drive were also placed in service in Minneapolis.

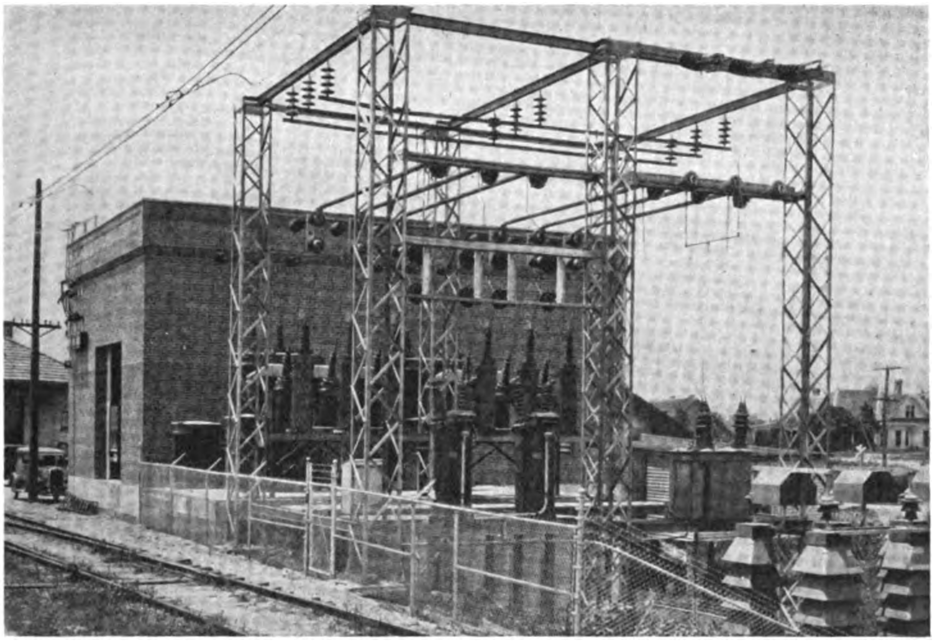


Fig. 38. Automatic Railway Substation with Outdoor Transformers
Piedmont & Northern Ry.

RAILWAY SUBSTATIONS

In the power substation field, notable advances were made in the mercury-arc power rectifier which is now being considered for practically all railway substations of 600 volts and above. The Delaware, Lackawanna and Western Railroad decided to use this apparatus exclusively for supplying power to its 70-mile electrification west from the Hoboken Terminal.

Five substations are being provided, containing a total of 13 units with an aggregate capacity of 37,000 kw. at 3000 volts direct current with high-speed breaker protection for the feeders. Central-station power from several independent supply points will be used for this project.

Work was progressing on a number of 1500-volt rectifier installations, including two new substations (duplicates of those installed recently), each containing a 750-kw. 1500-volt unit, on the Piedmont and Northern Railway (Figs. 38 and 39), a 1500-kw. 1500-volt unit in the Vollmer Road substation of the Commonwealth-Edison Company, supplying the Illinois Central Railroad, and two 2000-kw. 3000-volt units for use on one of the high-voltage lines in Italy.

A considerable number of 600-volt rectifiers are now being used by the railroads of the United States and Canada, including the following installations:

Three 3125-kw. 625-volt units for the Chicago Rapid Transit Company, supplying elevated and surface lines.

Two 1500-kw. 600-volt units for the Montreal Tramways.

One 500-kw. 600-volt unit in each of the Hague Avenue and Linden Substations of the Columbus Railway and Light Company. The Hague Avenue unit is arranged for operating in parallel with full-automatic control with an existing 500-kw. synchronous converter.

One 1000-kw. 620-volt unit installed by the Chicago-Joliet Railway in its Summit Substation, to be equipped for full-automatic control following experience with a 500-kw. unit.

One 1000-kw. 575-volt unit for British Columbia Electric Railway Company.

Three 1000-kw. 600-volt units for the Wyoming Substation, Philadelphia Rapid Transit Company.

One 500-kw. 1500-volt unit (Fig. 40) for the Sacramento Northern Railway.

The largest single-unit mercury-arc rectifier so far constructed will be placed in service by the

Consolidated Mining and Smelting Company at Trail (British Columbia). It consists of a 6500-kw. 650-volt tank which will be manually controlled.

An important conversion is being undertaken by the Omaha and Council Bluffs Railway, which is in effect a complete revamping of its entire power supply; the existing 25-cycle equipment being retained for emergency operation. There will be nine new 60-cycle substations, including one of 500-kw. capacity; all automatically controlled.

A change involving unusual features is being made by the New York Central Railroad Company in the

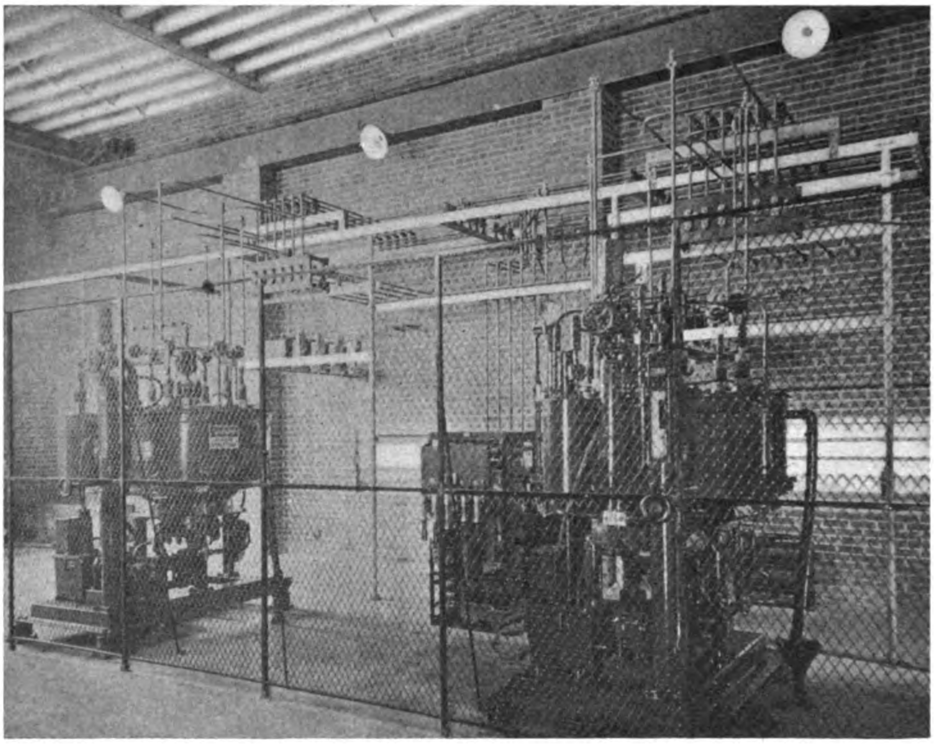


Fig. 39. Two 750-kw. 1500-volt Mercury Arc Rectifiers in the Substation Shown in Fig. 38

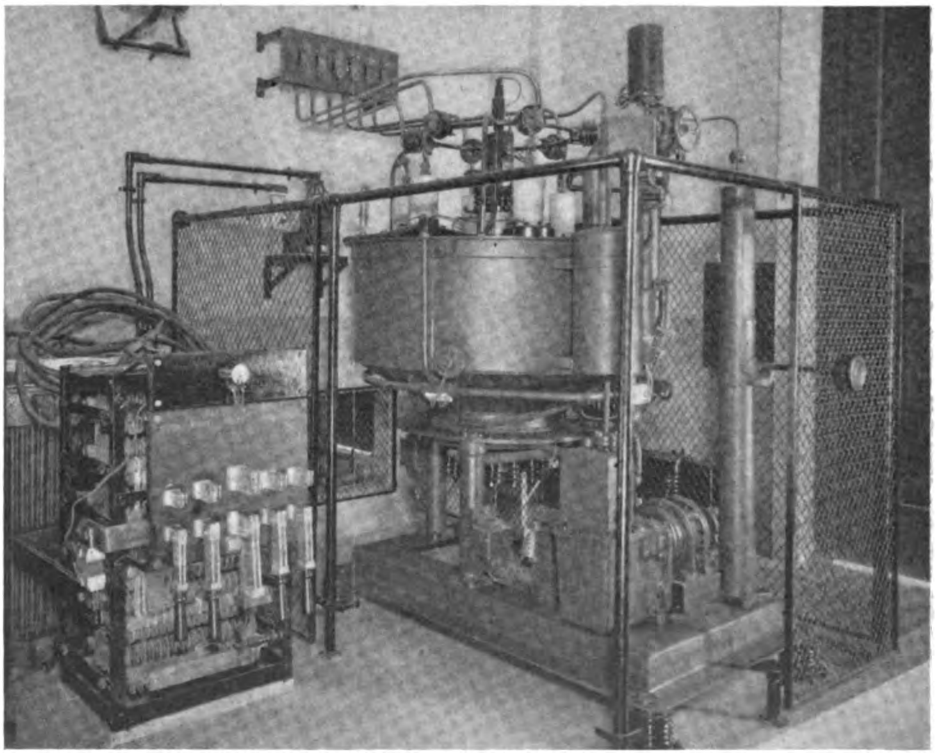


Fig. 40. 500-kw. 1500-volt Mercury-arc Rectifier in Substation; Sacramento Northern Ry.

substation supply arrangements at the Grand Central Terminal, which includes a new substation to be located 90 ft. below the street level. Some equipment will be transferred from the old Fiftieth Street Station and new apparatus including two 4000-kw. synchronous converters for 650 volts will be installed making a total of 17,000 kw. for railway power supply. Converters for lighting and power aggregate 8000 kw. Future extensions will bring this station to the exceptional capacity of nearly 30,000 kw. The switching equipment will be manually operated.

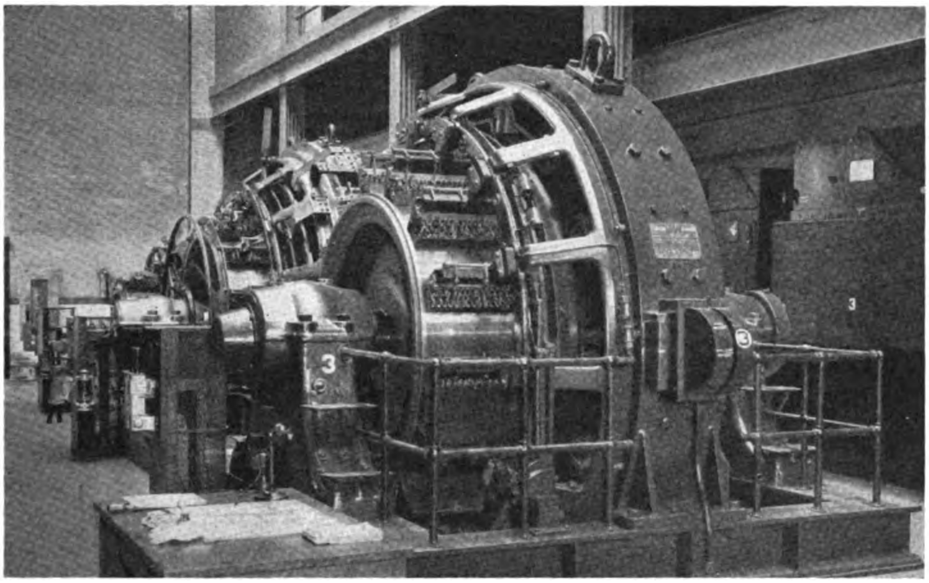


Fig. 41. 4000-kw. Synchronous Converters with Manual Control in Substation of Brooklyn-Manhattan Transit Co.

An interesting installation by the Hartford Electric Light Company for the Connecticut Company comprises three 2000-kw. manually-controlled synchronous converters to replace the previous 25-cycle power supply. A feature of this station is the use of automatic protection, including starting and running contactors which are remotely operated from a push-button control. In this connection the Connecticut Company is also operating a 1000-kw. 25-cycle synchronous converter which has been arranged to run inverted with suitable protection and field-control devices for supplying power to two outlying 25-cycle substations. This arrangement permits the use of central-station power for the entire system while still retaining some of the 25-cycle equipment.

The Board of Transportation of the City of New York is proceeding with the construction of a new tunnel in the Borough of Manhattan and the initial power will be supplied to this line from six new substations, all of which will be equipped with synchronous converters and complete automatic switching with supervisory control. The total capacity of these stations will be 53,000 kw.

Additional power supply for the Boston Elevated Rapid Transit Lines is being provided in the Harvard Square Substation by two 3000-kw. synchronous converters which will be operated with complete automatic switching and supervisory control. In the Auburn Substation, the additions consist of automatic switching and supervisory control for an existing 2000-kw. synchronous converter.

The Long Island Railroad Company is starting the operation of a new 4000-kw. synchronous converter (Fig. 41) in the substation at Sunnyside Shops, Long Island City. This machine will be provided with manual switching equipment.

Among the more important foreign installations are a complete automatic switching equipment for two 500-kw. 50-cycle synchronous converters on the lines of the Melbourne Metropolitan Tramways, Melbourne (Australia), a 1000-kw. 550-volt synchronous motor-generator set which will be placed in service by the tramway at Porto Allegre (South America), and a two-unit station containing four 750-volt 1000-kw. synchronous converters, to be operated two in series, by the Shonan Electric Railway of Japan.

WATERWHEEL GENERATORS

Four 77,500-kv-a. 13,800-volt 88.25-r.p.m. 3-phase 50-cycle vertical-shaft waterwheel generators were under construction for the Dnieper River Development in Russia. With an overall diameter of approximately 40 ft., they exceed in physical dimensions, as well as electrical capacity, any waterwheel generators previously constructed.

While these generators do not incorporate any radical departures from conventional mechanical and electrical design (Fig. 42), they are noteworthy because of the refinements in design and materials which have made possible the development of such large electrical machines. The inherent lightness of the fabricated and welded steel-plate construction is of decided advantage in view of the great distance over which the machines must be shipped from the factory to southern Russia.

A completely-enclosed recirculating ventilating system, utilizing surface air coolers, will protect the generators from the sand-laden atmosphere which at times prevails at the location of the dam.

The rotors, which will be of the laminated floating-rim type, will be supported on spring thrust bearings. The rotating load supported by each spring thrust bearing will be approximately 1,850,000 lb. Welded steel-plate radial-arm upper bearing brackets will carry the bearing loads.

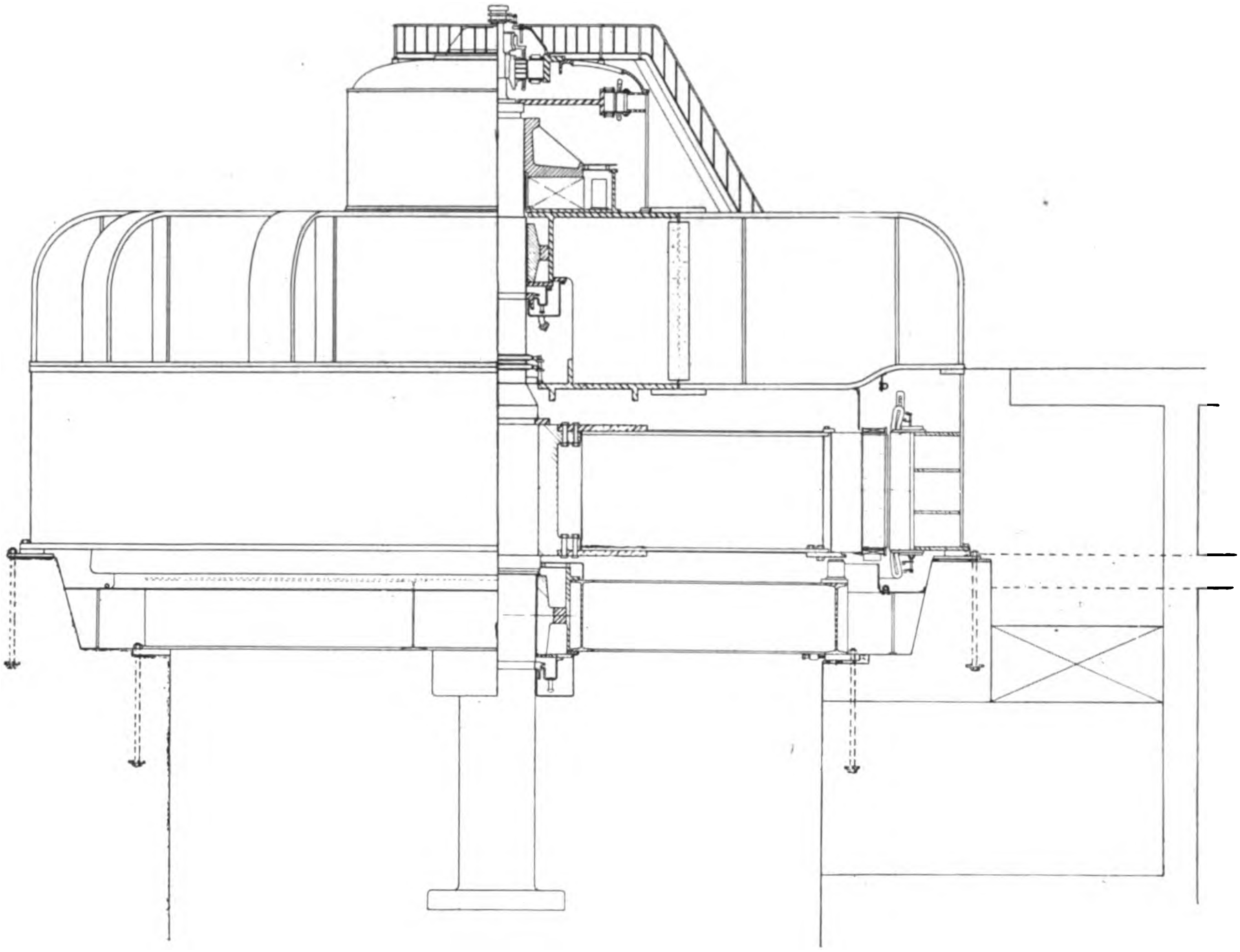


Fig. 42. Outline of Main Construction Features of Four 77,500-kv-a. Waterwheel-driven Generators

Each unit will be excited by a motor-generator set driven from an auxiliary generator direct connected to the main generator.

SYNCHRONOUS CONDENSERS

The first installation was made of an air-cooled synchronous condenser (Fig. 43) arranged with housing to permit outdoor operation. The machine is rated 15,000 kw., 900 r.p.m., 11,500 volts.

Air is taken in through filters from the outside and discharged through the base of the machine. Part of the warm discharge air may be diverted to heat near-by buildings. Coolers are placed in the incoming air stream through which the oil for the bearings is recirculated, in order to avoid the use of water cooling coils which might be a hazard in cold weather.

Sufficient air may be recirculated inside the housing to maintain a proper operating temperature during cold weather.

SYNCHRONOUS CONVERTERS

The first synchronous converter equipment to be put into commercial service with hydrogen as the cooling medium consists of two 3000-kw. 300-r.p.m. 300-volt direct-current shunt-wound sets for electrolytic work. An unusual feature of this installation is the fact that these machines will utilize hydrogen for cooling without the use of an explosion-proof housing.

The housing provided has a base plate which acts as a seal between the foundation and the machine, and the volute principle is utilized as part of the housing design and is arranged so that the hydrogen is recirculated through four straight coolers. It is expected that the hydrogen cooling medium will effect a saving of approximately one per cent in losses, as well as lengthen the life of the equipment and reduce maintenance costs.

These are the first large commutating machines to be provided with hydrogen cooling equipment.

DYNAMOMETERS

The largest electric dynamometer so far produced (Fig. 44) has a rating of 250 hp., 138/300 r.p.m., 250 volts. It will be used for the accurate testing of low-speed pumps.

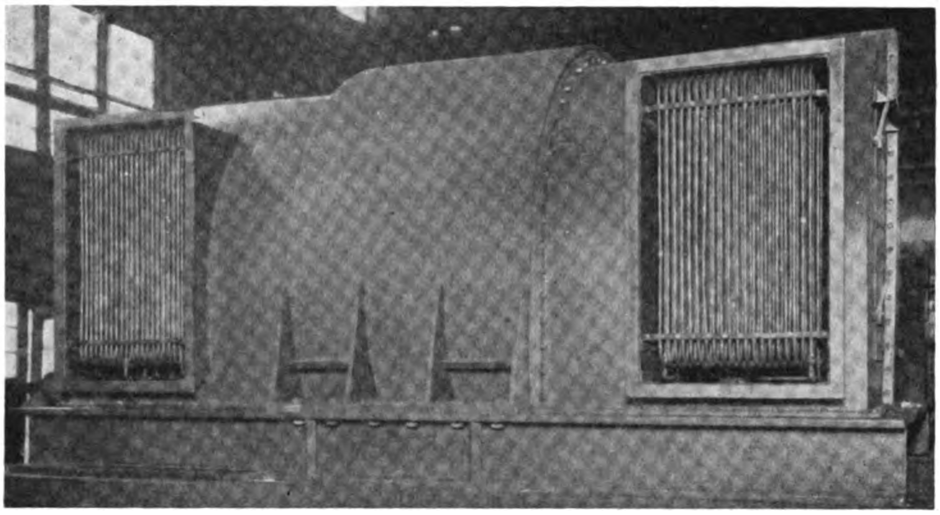


Fig. 43. 15,000-kw. 11,500-volt Outdoor Synchronous Condenser, Showing Arrangement of Cooling Coils in Intake Ducts for Cooling Bearing Oil by Recirculation

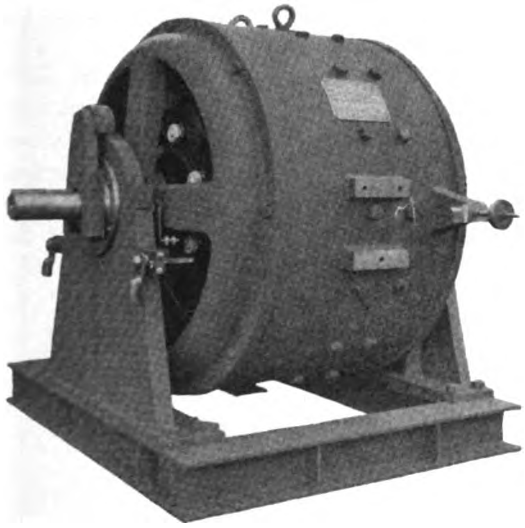


Fig. 44. 250-hp. 250-volt D-c. Dynamometer with Calibrating Arm

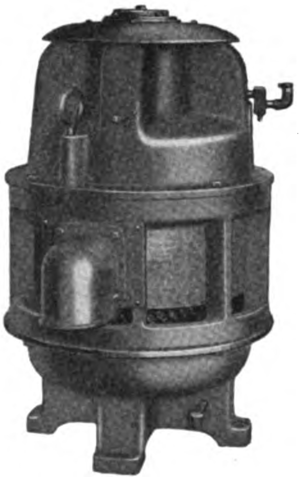


Fig. 45. 30-hp. 1800-r.p.m. 2300-volt Squirrel-cage Vertical Induction Motor

The rapid increase in production of larger airplane engines called for larger dynamometers for the accurate testing of these machines. The demand involved both increased capacities and higher speeds, and was met by supplementing the absorption capacity of electric machines with hydraulic dynamometers.

MOTORS

As a result of a very extensive survey of application requirements, a complete new line of vertical induction motors (Fig. 45) was developed in both solid shaft and hollow shaft construction.

The most important economic feature of the design is the limited number of base diameters utilized, the line being so proportioned that only three base diameters are used from the 1-hp. to the 150-hp. size. This feature is of value especially to pump manufacturers and other users of vertical motors who have heretofore been obliged to make pump heads varying in size with the ratings of the motors.

The smaller sizes of this new line have three different types of fabricated steel bases to fully meet the various needs of the small vertical-motor field.

The larger sizes, generally used where rather heavy thrust loads are encountered, have special thrust bearings providing greater thrust capacities, on a continuous basis, than have heretofore been available.

Many refinements of design were incorporated in synchronous motors, the more important being changes tending to lower the losses in these machines and to contribute in general to quietness of operation.

An important synchronous-motor application consisted of a 3000-hp. 125-r.p.m. unit for driving a reciprocating gas compressor; this being the largest synchronous motor yet applied for this class of work.

Another installation utilized seven 2000-hp. 93.8-r.p.m. and five 1200-hp. 83.3-r.p.m. synchronous motors for driving pumps capable of removing from 25,000 to 28,000 cu. ft. of water every second from a drainage system.

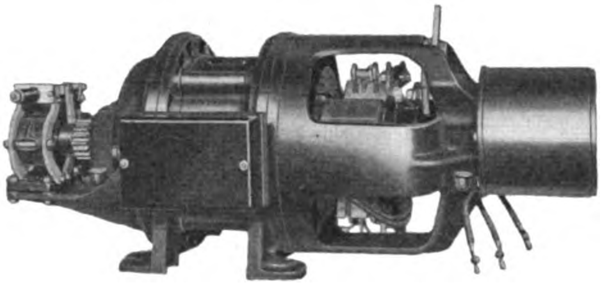


Fig. 46. 3-hp. 1650-r.p.m. 220-volt A-c. Brush-shifting Adjustable-speed Motor

As the sequel to a long series of tests in actual service, a group of two thousand 3-hp. adjustable-speed alternating current motors was applied in individual drive of full-fashioned hosiery knitting machines; this being the first commercial application of this type of motor to this particular service.

These shunt-characteristic motors (Fig. 46), in addition to the ease of changing the speed by simply shifting the brushes, are designed to give high starting torque, close speed regulation, and high power-factor.

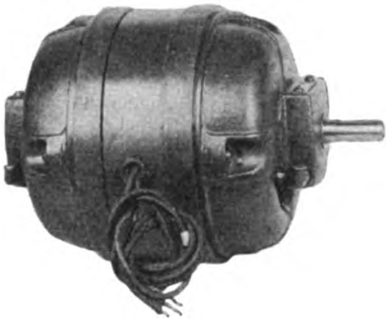


Fig. 47. Single-phase Capacitor Motor Designed for Operating Propeller-type Fans

The type of single-phase repulsion-induction motor which utilizes square stator punchings was extended to include larger single-phase ratings. The same magnetic structures were also used for a new line of single-phase capacitor motors (Fig. 47), particularly adapted for driving propeller-type fans. In addition to the novel round-frame construction utilized, these motors are provided with high-slip rotors which permit variable-speed operation when using a special control.

A departure from conventional construction was made in a small single-phase motor of the shaded-pole type. This is a 6-pole motor with a 2½-watt output, and is suitable for furnace control, small fans for home unit heaters and humidifiers, contactors and timers, advertising devices, and other applications which require only a very small amount of power.

This motor is of the usual shaded-pole construction but is unusual (Fig. 48) in that the squirrel cage is the external member and revolves, and the internal member is held stationary. The stator or internal member has the laminations assembled on a tube which has a bronze bearing in each end, and is extended at one end to provide the means of mounting the motor. The bearings are of unusual size for so small a motor, and an ample supply of lubricant is provided by a felt packing around the shaft between the bearings.

The external member or rotor is of the usual squirrel-cage type and is supported at one end by a spider which carries the shaft. The shaft comes back through the stator and the shaft extension comes out at the other end.

Another unusual feature of this motor is that only alternate poles are wound, making consequent poles out of the ones which have no winding. The advantages of this construction combine an unusually rigid and rugged bearing construction with economy of material due to the absence of the height of iron under the squirrel cage of the usual internal squirrel-cage construction. No case or end flanges are necessary and mounting is accomplished through one hole in a plate or support and held by one nut.

The six-pole speed eliminates some of the gear reduction in many applications as compared with the usual four-pole speed, and was adopted for that reason.

A new type of single-phase fractional horsepower motor, called the "reactor motor," (Fig. 49) was developed to meet the demand for a motor having split-phase characteristics but a very much lower starting current than was possible with an ordinary resistance split-phase motor. The motor employs a reactor in series with the "main" or "power" winding during the starting period, which is automatically short circuited at the same time that the starting winding is opened after the motor has started.

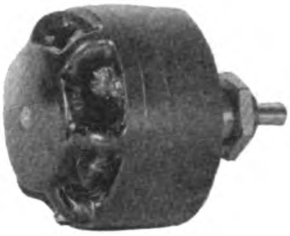


Fig. 48. 2½-watt 750-r.p.m. 110-volt 60-cycle Single-phase Motor

The reactor serves the double purpose of reducing the main-winding current and increasing its phase displacement, making a reduction in starting current possible with little or no sacrifice in starting torque. The reactor has been so compactly designed that it can be mounted directly on top of the motor; thus making the reactor motor a self-contained unit. These motors range in rating from ¼ hp. to 1 hp.

An adjustable varying-speed capacitor motor (Fig. 50) was developed particularly to meet the demand for an adjustable-speed motor to drive fans and blowers for such duty as ventilators and unit heaters. It consists simply of a two-phase stator and a high-resistance squirrel-cage rotor controlled by a capacitor unit with a speed-adjusting switch mounted directly on the case.

The capacitor is permanently connected in series with one phase of the stator winding, and serves to transform some of the input in such a manner that the motor operates like a polyphase induction motor. The other phase of the stator winding is connected to the speed-adjusting switch. The switch is of rotary snap construction and has four positions—high, medium, low, and off—which cause the motor to operate at approximately 90, 75, and 65 per cent of synchronism when driving a fan of rated capacity.

Two sizes of low-speed universal regulated constant-speed motors were produced for applications which require a low-output constant-speed universal motor with excellent accelerating characteristics for intermittent start and stop applications. The most important field for motors of this type at present is on office appliances.

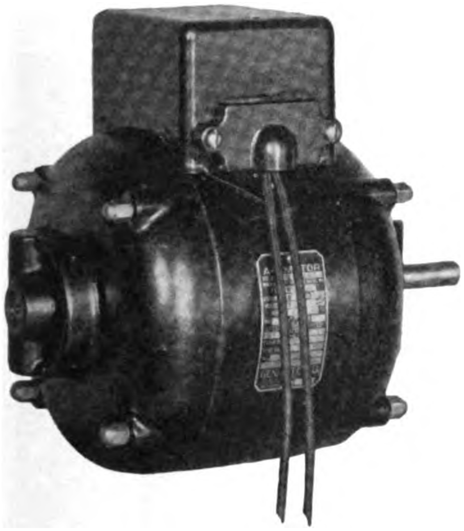


Fig. 49. ¼-hp. 1725-r.p.m. 110-volt 60-cycle Reactor-type Washing Machine Motor

Speed regulation is obtained by means of a centrifugally-operated contact mechanism which opens the line circuit of the motor when the speed exceeds the normal operating speed. A resistor and a capacitor are connected in parallel across the contacts of the regulator.

The motors are wound for voltages from 110 to 220 volts, and are universal over a frequency range from 60 cycles to direct current. The smaller size motor is designed for outputs up to 1/100 hp. at an operating speed of 2400 r.p.m. and the larger size for outputs up to 1/36 hp. at 1800 r.p.m.

CONTROL DEVICES

A new hydraulic operator takes the place of large alternating-current or direct-current magnets and solenoids, and may also be used to replace air cylinders where quiet and smooth upward thrust is desired through a definite distance. The device can be applied to brakes, clutches, door and window openers, hoists, small punch presses, spot welders, pumps, and many other mechanisms formerly operated by solenoids and air cylinders. It consists of a motor-driven centrifugal oil pump (Fig. 51), the impeller of which is mounted in a piston and driven by means of a spline shaft. This arrangement permits the stationary mounting of the pump motor.

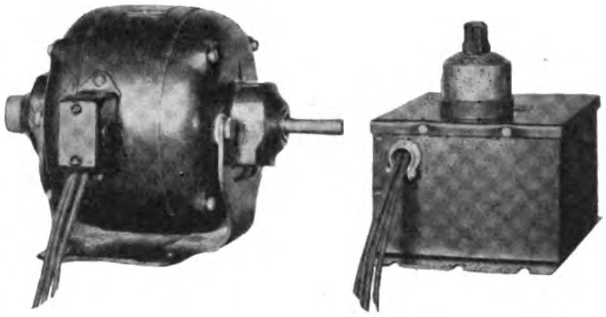


Fig. 50. ⅙-hp. 1080-r.p.m. 110-volt Adjustable, Varying-speed Capacitor Motor

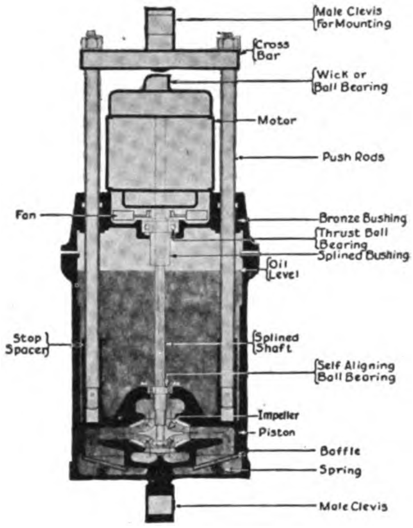


Fig. 51. Working Parts of New Hydraulic-type Motor-driven Operator

In the normal position the piston is at the bottom of the cylinder which is approximately two-thirds full of oil. When energized, the motor drives the impeller creating a pressure between the bottom of the piston and the bottom of the cylinder.

The piston is cast so that the oil is fed to the center of the impeller from both the top and the bottom. The oil is forced from the end of the impeller blades through ports to the space below the piston. The pressure tends to move the piston upward and it will travel the full length of the cylinder, providing the load on the ends of the push rod is not too great.

The load on the motor remains practically constant at slightly less than full load so long as there is any movement of the piston in the upward direction. As soon as the piston is stalled, the power consumed by the motor drops to approximately one-half of full load.

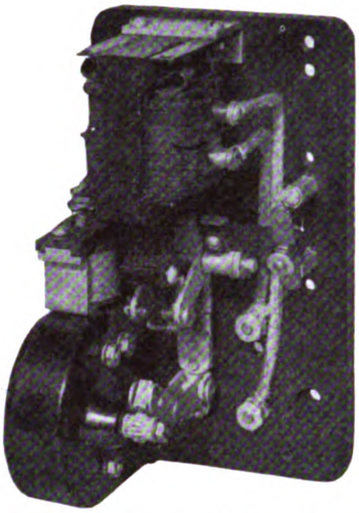


Fig. 52. Field Relay for Synchronous Motor with Definite-time Element and Lockout Coil

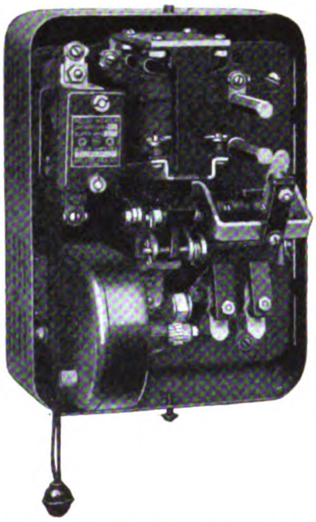


Fig. 53. Definite-time Automatic Starter for D-c. Motor

When the motor is deënergized, the oil friction slows down the impeller, decreasing the oil pressure, and the external load forces the piston down.

A relay (Fig. 52) for applying the field of a synchronous motor at the proper time consists chiefly of a definite-time element with a lockout coil. The lockout coil prevents the timing mechanism from operating until the synchronous motor accelerates to approximately 95 per cent of synchronous speed when the voltage decreases and allows the lockout coil to release the timing mechanism.

A new line of printing-press controllers for direct-current motors utilizes definite-time acceleration, which is essential in order to give the proper delay in accelerating to printing speed. The present speed is obtained by an external handle which actuates the rheostat; thereby regulating the amount of resistance in the field circuit. As compared with the previous controllers for this service, the new line reduces the number of contactors required and provides superior definite-time control.

A small and compact three-point definite-time starter (Fig. 53) was developed for direct-current motors rated ¾ to 3 hp., 115 and 230 volts. Although there is a reduction in the size over previous designs, the number of accelerating points is actually increased. Definite-time acceleration is adjustable over a range from two to eight seconds.

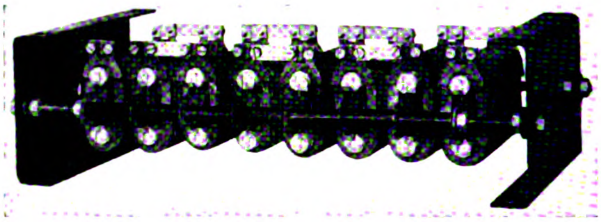


Fig. 54. Resistor Utilizing Insulators of Fused Alumina Compound

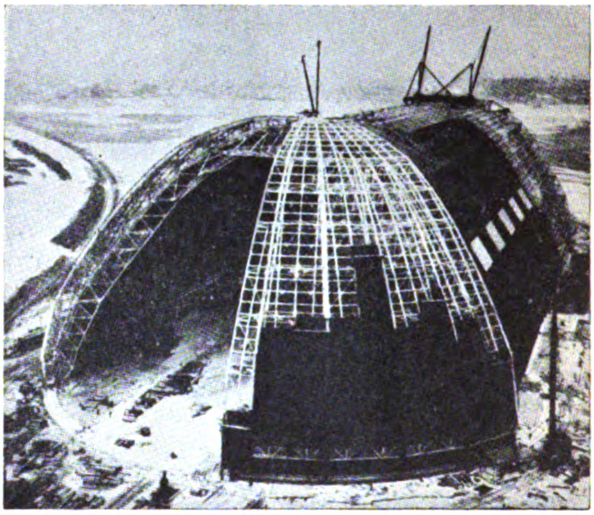


Fig. 55. Motor-operated Door Under Construction; Airship Factory of the Goodyear-Zeppelin Corp., Akron (O.).

Resistors are used in such large numbers that, broadly considered, any improvement in them is of great economic value to industry in general.

An edgewise-wound resistor (Fig. 54) embodying three new features was developed. It utilizes insulators of fused alumina compound, a material many times stronger than porcelain and maintaining a higher dielectric strength when heated to high temperatures. The terminals are brazed to the resistor ribbon, thus preventing all loose joints and terminal burn-outs, and elongated windings permit more length of ribbon per turn hence more watts per cubic inch, resulting in more compact units for the dissipation of a given amount of energy.

The resistor is of light weight and utilizes stainless-steel ribbon which insures a low temperature coefficient of resistance. It has double insulation to ground.

MOTOR APPLICATIONS

The mammoth airship factory of the Goodyear-Zeppelin Corporation at Akron (O.), is provided with motor-operated "orange-peel" doors (Fig. 55) of a unique type. These doors are each 202 ft. high, 214 ft. wide, at the base, and rest on 40 wheels.

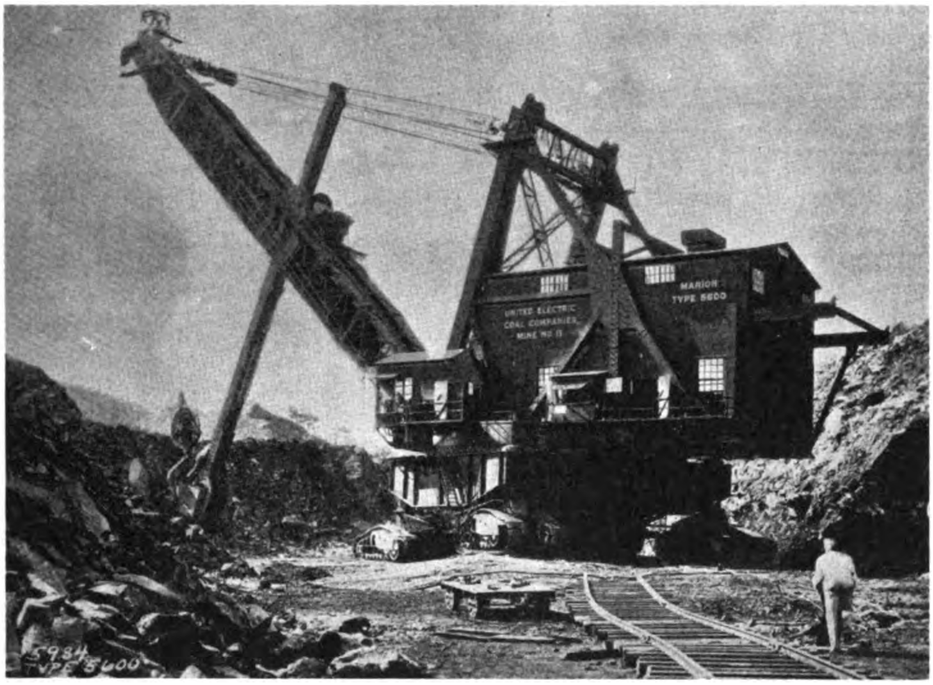


Fig. 56. 1800-ton Marion Electric Shovel at the Fidelity Mine of the United Electric Coal Companies

Each door weighs about 600 tons and, as its mass must be under control at all times, it is operated by a rack-drive system actuated by a gear train which is in turn driven through a worm gear by a motor. The actual rating of the four motors supplied for the four doors is 200/100 hp., 600/300 r.p.m., 440 volts, 3 phase, 60 cycles, based on a 15-min. rating.

Electric brakes were also provided, capable of giving a retarding torque of approximately 1200 lb-ft. They have an inherent time delay of 1½ to 2½ sec. With this equipment, these huge moving masses can be positively controlled by means of push-buttons.

The Owyhee Dam at present being built in Oregon is higher than any dam heretofore constructed in the United States. In connection with this work, a cable-way driven by a 400-hp. slip-ring motor is utilized.

A novel feature in this equipment consists of the control which is exercised through 2000 ft. of control cable, so that the operator, while on the dam and at this distance from the movable cable-way tower which contains the operating mechanism, is at all times able to direct and control the movements of both tower and cable-way.

Electric Shovels

A mammoth electric shovel now working at the Fidelity Mine of the United Electric Coal Companies is interesting in many ways apart from its record size.

The weight of the shovel on its tractors (Fig. 56), when ballasted and in actual operation, is 1800 tons and with its 120-ft. boom and 85 ft. dipper stick it can strip or uncover coal lying at a depth of approximately 60 ft.; the maximum previous depth being about 40 ft.

The electrical equipment consists of a 1700-kv-a. synchronous motor, driving an 860-kw. hoist generator, a 350-kw. swing generator, and a 350-kw. crowd generator. The hoist proper is equipped with two 450-hp. motors, the swing with two 150-hp. motors, and the crowd with two 150-hp. motors. There is also a large amount of auxiliary apparatus, such as air compressors, transformers, etc. In all, the total electrical horsepower installed is somewhat in excess of 4000.

The shovel to date has been working in a rather narrow cut and making a complete cycle of 65-deg. swing in 47 sec. This means that the shovel will dig, swing, dump, swing back, and start digging again in 47 sec.

Mine Hoists

A converted automatic mine hoist put into operation by the Miami Copper Company has a larger horsepower rating and operates at higher rope speed than any automatically-controlled hoist heretofore used in mine service in the United States.

The original mine hoist was driven by a 1400-hp. 325-r.p.m. hoist motor, geared to the drums, and, in order to increase the hoisting speed, a second motor of the same capacity was also direct-geared to the hoist, making a total of 2800 hp. so applied. Current is supplied to the hoist motors from two 1000-kw. flywheel-type motor-generator sets. These two equipments, the motor and the motor-generators, are connected in series. The hoist has an operating capacity of 980 tons per hour from a depth of 720 ft. with a rope speed of 2250 ft. per min.

A tunnel approximately 21 miles long, which will have a finished inside diameter of 19 ft., will constitute a part of the water-supply system for the City of New York. This is the largest single undertaking of its kind in the United States, and the construction equipment includes 16 hoists, each driven by a 250-hp. 500-r.p.m. motor, the current supply for each being obtained from a synchronous motor-generator set consisting of a 350-hp. 1200-r.p.m. synchronous motor, a 200-kw. generator, and a direct-connected exciter.

The control is of the semi-automatic type, arranged for operation by an attendant located at the collar of the shaft.

Mine Locomotives

For the first time, a practical gearless cable-reel equipment was developed for mine-haulage locomotives which, by means of the direct drive (Fig. 57), eliminates not only the gears heretofore required but reduces the number of wearing parts and simplifies the lubrication.

The reel is driven direct by the armature shaft and thus revolves at the same speed as the motor armature, the vertical load being carried by a tapered roller bearing at the top of the armature shaft. A roller bearing is also used on the lower end. A sheathed-wire type of resistor is used with the reel motor.

There was a notable increase in the use of roller bearings in the construction of all types of industrial and mine-haulage locomotives.

STEEL MILLS

Intense activity in the steel industry was evidenced not only by the increased production of steel but by the number of new mills built and mill drives installed. During the year, G-E motors of 300-hp. capacity and above, totaling more than 182,800-hp. were provided for driving the main rolls of metal-rolling mills. This is in excess of the capacity installed in any previous year.

Approximately 70 per cent of the total was in direct-current adjustable-speed units which were adopted to insure the necessary flexibility in mill operation to meet the speed changes involved in the production of a considerable variety of products. This flexibility is best obtained by the use of individual adjustable-speed motor drives, and accounts for the increasing proportion of direct-current motors used.

Synchronous motors were used for main-roll drives in increased numbers.

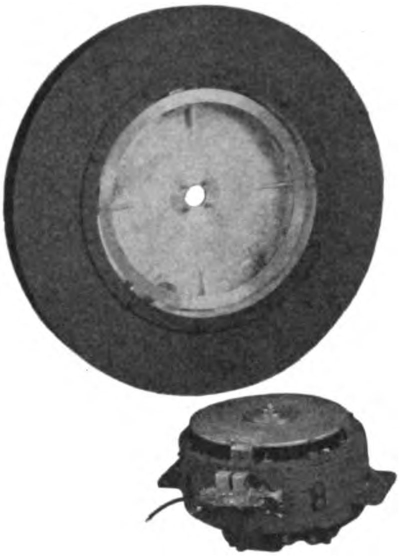


Fig. 57. Gearless Cable Reel and Motor for Mine-haulage Locomotive

As evidence of the extent to which adjustable-speed individual drive is being carried, a 10-in. merchant mill at the plant of the Inland Steel Company, Indiana Harbor (Ind.) will be driven by thirteen direct-current motors totaling only 4900 hp. In a large number of drives of this type, the direct-current power is furnished to the mill motors from one or more motor-generator sets which are used in connection with one mill only. This permits the starting up of the mill motors by control of the generator voltage, thereby eliminating the necessity for rheostatic starting apparatus.

A continuous copper mill of the National Electric Products Company of Bayway (N. J.), which will deliver copper rod at extremely high speed, will use adjustable-speed direct-current motors totaling 3000 hp. for the drive.

Early in the year, the Wheeling Steel Corporation put in operation at its Steubenville (O.) plant, the first electrically-driven reversing universal slabbing mill in this country. The drive involves two reversing motors, one of 7000 hp. on the horizontal rolls and one of 1650 hp. on the vertical rolls; and the control is arranged so that the two motors accelerate, decelerate, and reverse simultaneously, and maintain the correct speed ratio.

An unusual installation consists of two concatenated induction motors at the Calgary (Alberta) plant of the Manitoba Bridge and Iron Works. One of these units is rated 1200 hp., 600/400 r.p.m., and consists of one 1200-hp. 600-r.p.m. and one 400-hp. 400-r.p.m. wound-rotor motors. The other is rated 700 hp. 900/720 r.p.m., and consists of one 700-hp. 900-r.p.m. wound-rotor motor and one 140-hp. 720-r.p.m. squirrel-cage motor. In each case, the two motors composing the unit are mounted on a common shaft and base.

The A. M. Byers Company developed a new process which is expected to reduce the cost of producing wrought iron. This company is building a new plant at Ambridge (Pa.) and will install a 5000-hp. reversing motor for driving a blooming mill, a 4000-hp. reversing motor for driving a reversing plate mill, and six direct-current motors totaling 9300 hp. for driving mills which will produce the skelp from which wrought iron pipe is formed. Contrary to the usual practice, the motor-generator set which supplies power to the 4000-hp. reversing motor will not be equipped with a flywheel, but will be driven by a synchronous motor.

The Illinois Steel Company is installing at its Gary Plant a wide-strip mill which will be driven by direct-current motors throughout, totaling more than 20,000 hp. This is probably the first wide-strip mill on which all stands are driven by direct-current adjustable-speed motors, previous mills having used alternating-current motors on the roughing stands.

A high-speed continuous hot-strip mill at the plant of the Sharon Steel Hoop Company has the finishing stands spaced on such close centers that it was necessary to keep the external diameter of the driving motors to an absolute minimum. Six 1250-hp. adjustable-speed direct-current motors, three of them of single-armature construction and three of double-armature (Fig. 58), are therefore mounted on a common base-plate. For this same mill, a double-armature direct-current motor rated 4500 hp., 150/450-r.p.m. is used, and to build a motor of this capacity to cover the specified speed range involved exceptional problems in design.

For a new steel mill being erected in the Detroit district by the Great Lakes Steel Corporation, drives for various strip mills involving 19 direct-current motors totaling 33,600 hp. will be required, together with several 5000-kw. motor-generator sets for furnishing power to the main-drive motors.

A unique type of control equipment was developed for a so-called "Steckel" cold-rolling mill. In this type of mill, the rolls which perform the reduction on the metal are not driven but the strip is pulled through them by means of a motor-driven reel on which it is wound. One of these reels is placed at each side of the main-roll stand, and the strip is passed back and forth through the rolls, being wound on one reel as it unwinds from the other. It is essential that a certain amount of tension be maintained in the strip between the roll stand and the reel from which it is being unwound, so that when one of the reels is being driven by its motor, the motor on the other reel is acting as a generator to produce tension in the strip. The tension must be accurately controlled and, therefore, regulators are used to maintain constant load on the machine which is acting as a generator.

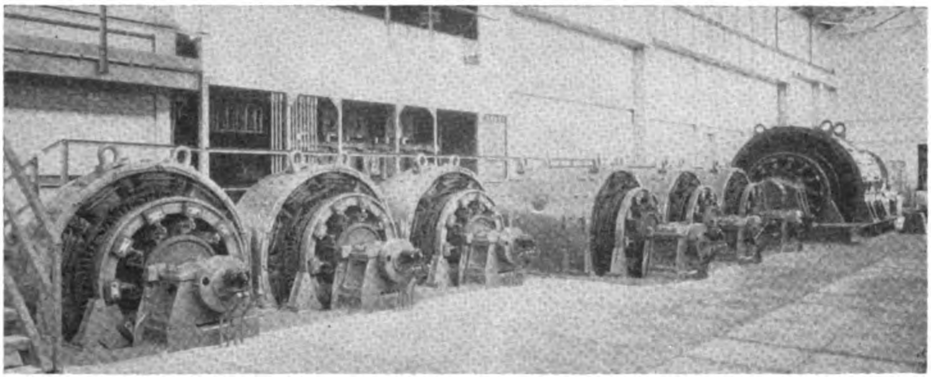


Fig. 58. Six 1250-hp. D-c. Motors Mounted on Common Bed-plate Driving Hot-strip Mill; 4500-hp. Roughing-mill Motor in Background, Sharon Steel Hoop Company, Sharon (Pa.)

In the past, the majority of "live-table" rollers, which carry hot steel from one mill stand to another or to the cooling bed, have been driven by connection through bevelled gearing to a line shaft which was in turn driven by a motor. It is now becoming quite common practice to drive each individual table roll by means of a small induction motor. For a special type of table roller, known as the "Schloemann motor roller," a line of induction motors of very special construction was designed. The motors are placed inside of the roller itself, which is hollow. Contrary to the usual method of construction of squirrel-cage motors, the rotor is placed external to the stator winding. The stator laminations are mounted on a shaft which is held stationary and the roller, with the squirrel-cage rotor fastened to its internal surface, rotates in roller bearings mounted on the shaft.

ARC WELDING

There was an increasing use of electric arc welding in the fabrication of structural-steel buildings, bridges, etc., and the building codes of many cities were changed to permit welded instead of riveted structures. The demand of the public for the elimination of the noise of riveting hammers in construction work is becoming more insistent.

Many of the new steel pipe lines for the transportation of natural gas and oil are being laid with electrically-welded girth joints. The field welding of these joints is being done by gasoline-engine-driven single-operator welding sets; and for this service a single-operator welding set (Fig. 59) consisting of a 300-amp. welding generator driven by a Buda six-cylinder gasoline engine was produced.

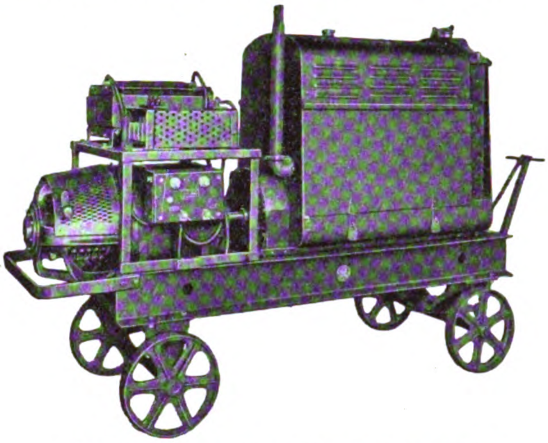


Fig. 59. 300-amp. 25-volt Portable Arc-welding Engine-generator Set

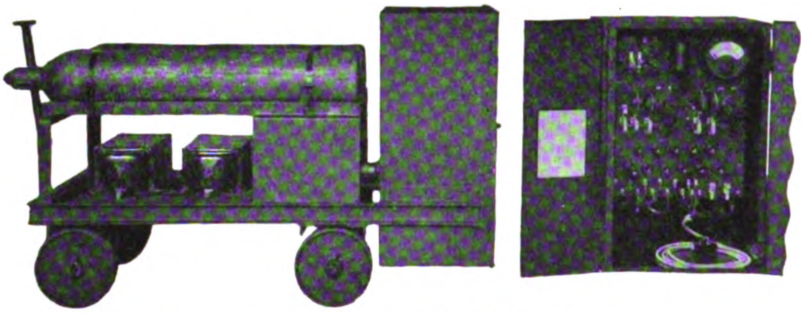


Fig. 60. Portable Atomic-hydrogen Welding Equipment

The manufacture of steel pipe for gas and oil lines from flat plates rolled into cylindrical form with the longitudinal joint arc welded increased, and much of this welding is now done with relatively high welding currents. There was designed for this work an 800-amp. one-hour-rated single-operator welding generator.

The wider application of the atomic-hydrogen method of electric welding (Fig. 60) necessitated the development of a portable equipment.

A self-propelled automatic arc welder was developed for welding building floors, bridge floors, ship decks, oil storage tank tops and bottoms, etc. It was demonstrated on a steel floor at Biloxi (Miss.) at the convention of the American Institute of Steel Construction, Inc.

The equipment consists of a small self-propelled carriage (Fig. 61) approximately 2 ft. long, 15 in. wide, and 2 ft. high, upon which is mounted a standard automatic arc-welding head. The carriage is driven by an adjustable-speed motor and has a speed range of 6 to 24 in. per minute.

Welding was done at Biloxi on a $\frac{3}{16}$-in. steel floor at a speed of 9½ in. per minute, using 275 amp. and 22 volts in the arc and a $\frac{3}{16}$-in. diameter electrode.

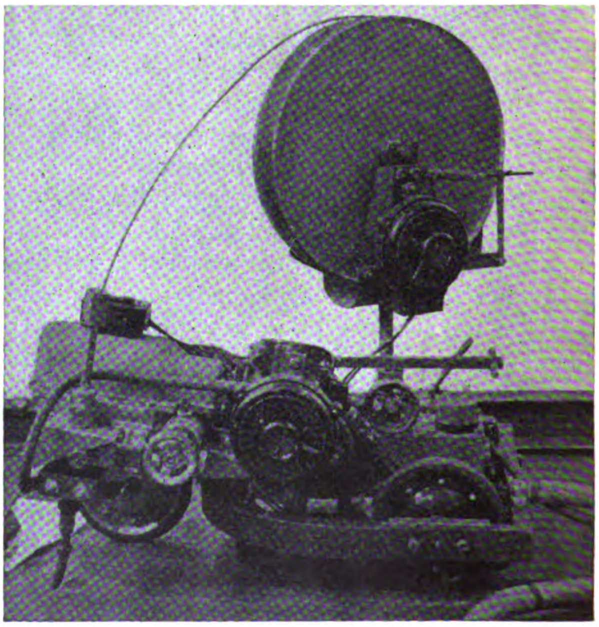


Fig. 61. Self-propelled Automatic Arc Welder

INDUSTRIAL HEATING

A new vertical cylindrical furnace incorporating a motor-driven agitating fan was designed for nitriding or for high-temperature air drawing. It is suitable for operation at temperatures up to 1250 deg. F. and the agitating fan provides a constant circulation of air around the work which permits a production practically double that obtained from a still-air furnace of similar size. In operation as a drawing furnace the removable gastight alloy retort which is used for nitriding is removed and the charge, which is contained in a metal basket, is exposed directly to the heating units.

The larger sizes of a standard line of box-type furnaces for general heat treating were redesigned.

They combine the use of a special light-weight refractory brick with a radically new design of furnace front (Fig. 62) which incorporates a motor-operated door lifted by two jack screws. The door is controlled by push buttons and protected with limit switches at both top and bottom ends of the travel. Provision is made for preventing the door being jammed at the top or bottom in case of the failure of either limit switch. Arrangement is also made for the manual operation of the door if the power goes off while a charge is in the furnace.

A mesh-belt conveyor furnace was designed to meet an increasing demand for a means of continuously heat treating large quantities of small parts. It is of rectangular form (Fig. 63), about 12 ft. long, 6 ft. wide and 6 ft. high overall, and will handle up to 300 lb. per hour of shapes up to 16 in. in length and 2½ in. cross-section. The principal features are the automatic feed and discharge which are accomplished by a mesh-belt conveyor of heat resisting alloy. This makes it possible to give identical heat treatment of all pieces with a minimum of handling.

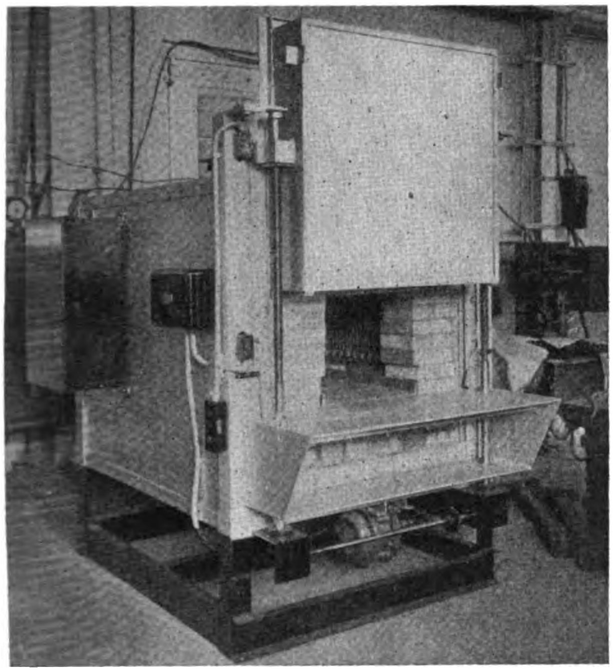


Fig. 62. Box-type Furnace with Motor-operated Door and Fabricated Steel Front

One of the most important advances of recent years resulting from the application of electric heat to industry came about through the development of the short-cycle anneal in the production of malleable iron. This has effected a reduction in the annealing time from around 180 hr. to between 24 and 30 hr.

In the old process, parts to be annealed were packed into tight boxes, placed in fuel-fired furnaces, and heated for the time required. No boxes are required in the new process, the iron being stacked directly on the floor of the car which forms the bottom of the bell-type or elevator-type electric furnace used.

The process consists of, first, heating the work in a high temperature furnace to effect a solid solution of the free cementite present in the iron. This being accomplished, the car bottom of the furnace with its load is transferred to a low temperature furnace where the cooling and drawing is effected by causing the iron to pass through a carefully worked out series of temperature changes. So sensitive is the process to temperature during the anneal that the electric furnace will give the most desirable results.

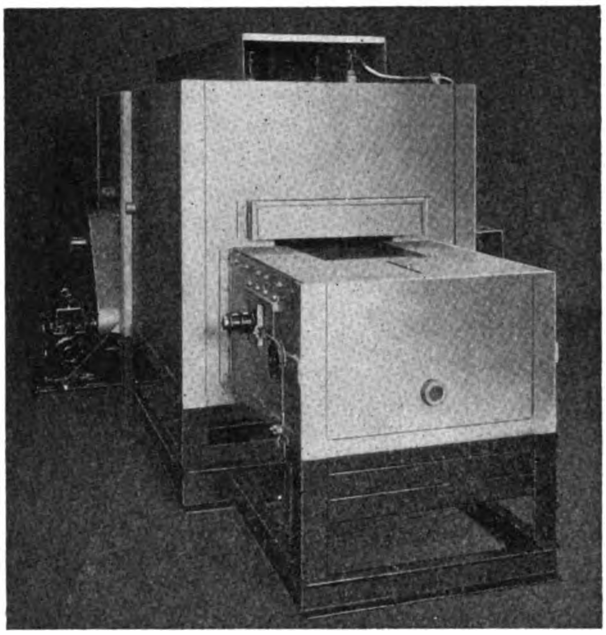


Fig. 63. 45-kw. 2-circuit Mesh-belt Conveyor Furnace

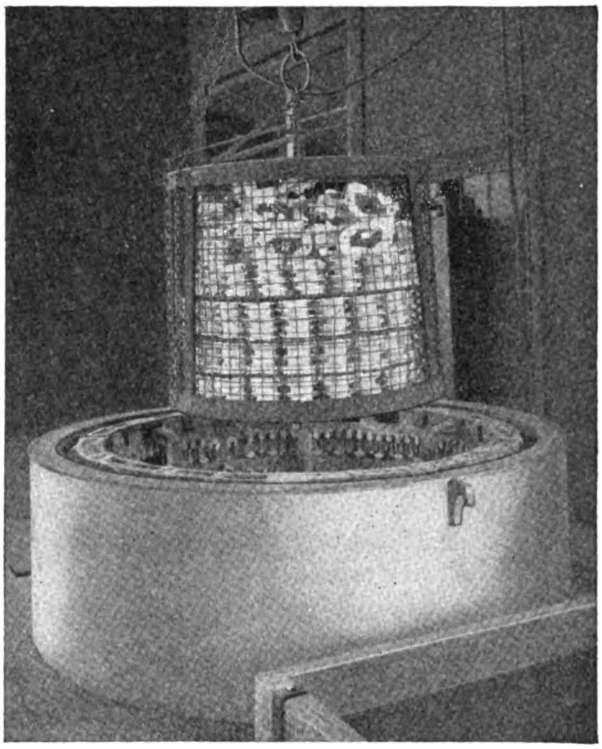


Fig. 64. 84-kw. Pit-type 220-volt 3-phase Electric Furnace for Heat-treating Aluminum-alloy Castings

A new electric furnace especially designed to heat treat aluminum alloys is of the cylindrical unit-pit type having two circuits; one, rated 220 volts, 3 phase with a Y-series connection, in the top; the other, in the lower side walls and bottom, rated 220 volts, 3 phase with a Y-delta connection. At high heat the power consumption is 84 kw.; and at low heat, 28 kw.

In a typical application of this furnace (Fig. 64) a run of castings weighing approximately 500 lb. plus a basket weight of 700 lb., both at room temperature, was placed in the furnace at a temperature of 960 deg. F. In 1½ hr. the center of the charge was at the heat-treating temperature, although for a third of this time the furnace was operating on low heat. A check showed that the outside of the charge next to the heating units was no higher than 960 deg. F.

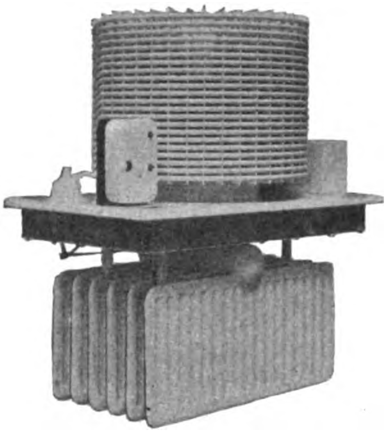


Fig. 65. Improved Refrigerating Machine with Multiple-plate Type Evaporators

In this typical furnace the working dimensions are a diameter of four feet and depth of six. It was designed to heat a charge weighing 1500 lb., plus a basket weight of 500 lb., from 600 to 950 deg. F. in one hour, and to hold the charge at the latter temperature for 12 hr. The estimated radiation rate at the holding temperature is 17 kw-hr.

An improved type of strip heater, a localized heating unit for either air or "clamp-on" heating, is essentially like the well-known sheath wire unit in construction, embodying as it does a coiled nickel chromium resistance wire, embedded in highly compressed magnesium oxide powder, all encased within a flat steel tube having no seams.

ELECTRIC REFRIGERATION

The adoption of electric household refrigeration greatly exceeded the records of previous years. The electric refrigerating unit was also adapted to a variety of commercial equipments, and a new refrigerating element was developed for this class of service.

The new refrigerating machines are of greater capacity than the domestic sizes, they have larger motors, the compressors are of two-cylinder construction, and the condensers have a double row of tubing. The evaporators (Fig. 65) are of the defrosting, multiple-plate type and combine maximum evaporating surface with vitreous porcelain finish.

Units of this type were applied to a variety of refrigerator cabinets ranging from 27 to 60 cu. ft. in storage capacity, and, with slight modifications, they were also applied to a self-contained submerged can-type milk cooler which has a capacity for cooling four 10-gal. cans of milk every 24 hr. The milk cooling is accomplished by means of a water-bath surrounding a coil evaporator on which a blanket of ice is frozen during the operation of the machine.

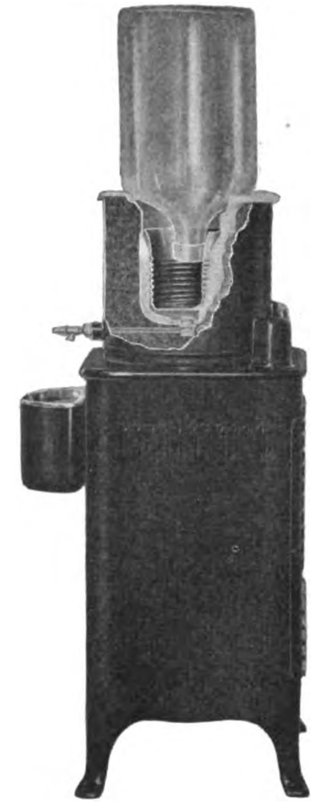


Fig. 66. Typical Bottle Water-cooler Utilizing Refrigerating Electric Unit

A completely sealed refrigerating machine is used to hold the interior of this cabinet at any desired temperature down to zero degrees F. and an external temperature adjustment is provided in addition to the usual automatic control.

A bottle water-cooler of five-gallon capacity (Fig. 66) was designed to replace the old ice-cooled type of drinking fountain. The compressor unit used in this installation is suspended on steel cables under the evaporator. The cooling chamber or evaporator consists of two drawn cylindrical steel shells, welded and copper brazed together, having a porcelain enameled finish.

The evaporator is heavily enameled both inside and out, and a baffle cup is set in the evaporator which directs the flow of the water against the cold walls of the evaporator on its way to the faucet.

The most recent addition to household refrigeration equipment is a type of refrigerator especially designed for small apartments. It is intended to be located in the space under the drainboard of the apartment kitchen sink. In this instance, the compressor unit is secured to the side of the cabinet, thereby giving sufficient clearance between the sink trap and the top of the compressor unit. This refrigerator has a food storage capacity of 3½ cu. ft.

RESEARCH

Thermocouple

By means of a new high-temperature thermocouple, having a useful range from 500 to 2400 deg. C., it is now possible for the first time to measure directly and with considerable accuracy, the temperatures of open-hearth steel furnaces, the steel in the pouring ladle, the melting of quartz, etc. This thermo-couple is composed of tungsten and graphite, and constitutes a new tool which in the hands of the industrial-control engineer extends the range of automatic control of temperature upward by 800 deg. C., as compared with previous practice.

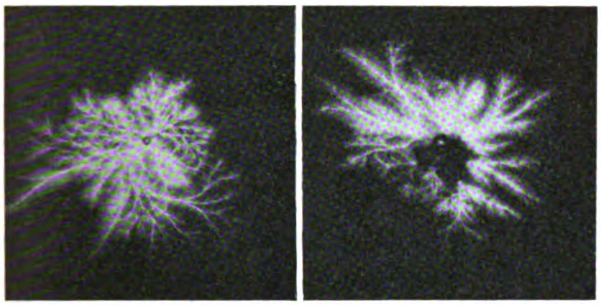


Fig. 67. Record of a Direct Lightning Stroke Taken with the Lightning Stroke Recorder, Showing (Left to Right) Top Film and Bottom Film

Lightning Research

The lightning-research program which has been carried on for several years in coöperation with various power companies was continued during the year. Lightning laboratories, containing cathode-ray oscillographs, surge-voltage recorders, lightning-stroke recorders (Fig. 67), cloud-field intensity meters, and rate of change of cloud-field meters, were established and operated in coöperation with the Pennsylvania Power and Light Company and the Ohio Power Company.

These laboratories yielded about 100 cathode-ray oscillograms of wave form of surges on transmission lines caused by lightning (Fig. 68), also considerable data on the magnitude of surges, cloud-field intensity, and a limited amount of data on direct strokes.

Much information of value was obtained from the study of travel of impulses on overhead transmission lines. This work was carried out on the lines of the Turners Falls Power and Electric Company, in western Massachusetts, and also in Michigan, on a line extending from Croton Dam to Grand Rapids, which is a part of the Consumers Power System.

At Pittsfield, in May, 1929, tests were made with a portable million-volt generator (Fig. 69) with the normal (66 kv.) operating potential on the system. At this time tests were made on lightning arresters under actual conditions of service. Subsequently, on the same circuit, a study was made of choke coils which resulted in the discontinuance of the choke coil as an accessory to the arrester. Attenuation studies, including the effect of the ground wire were also made. In Michigan, a similar generator (Fig. 70) has been in continuous use since May, 1929, for studying the effects of ground wires, tower footing resistance, attenuation, surge impedance, and many other factors, all of which have already made clearer the picture of what happens on lines under lightning conditions. This work is an outgrowth of the work begun in 1928 on the Turners Falls Power and Electric Company's line, which was the first application of high-voltage transients to actual high-voltage transmission lines.

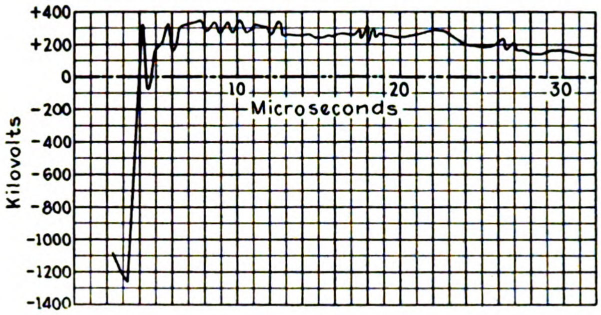


Fig. 68. Typical Lightning Surge Oscillogram, Showing Peak of Voltage at the Point of Flashover

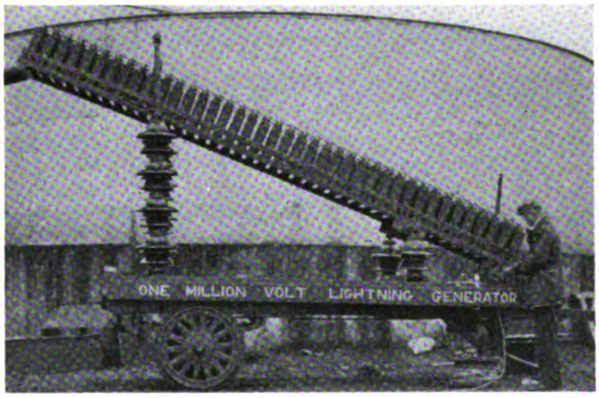


Fig. 69. Portable Million-volt Impulse Generator for the Study of Surges on Transmission Lines

The million-volt generator is mounted on an automobile truck trailer for field service. The principal element consists of a rack on which eighty 25,000-volt condenser units are connected as a series of 40 pairs. By means of a transformer connected to the customary 110-volt lighting circuit, these condensers are charged to the limit of their capacity and then discharged—practically instantly in 40 successive sparks from the bottom of the rack to the top, so that the final discharge into the transmission line is at a million volts. The charges can be shot into the line at the rate of about one each minute, and any desired number of such shots can be generated in rapid succession.

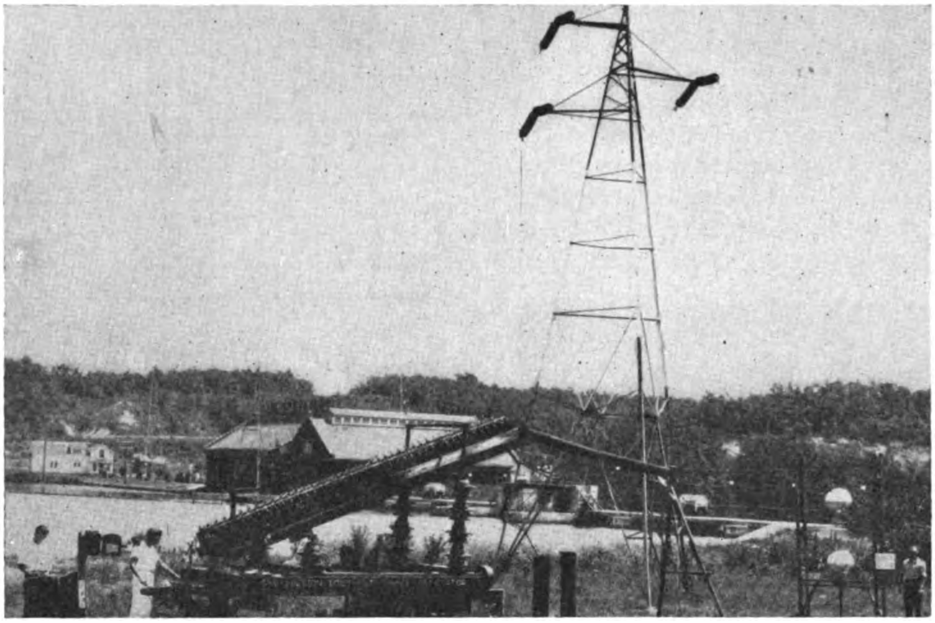


Fig. 70. Portable Million-volt Impulse-generator Equipment Arranged for Field Work on Transmission System

Film Phonograph

There are two methods of recording sounds photographically on film, known respectively as the variable-width and variable-density methods. In the latter, a narrow slit of light is focused transversely on the moving film and the amount of light passing through the slit is varied in accordance with the amplitude and frequency of the sound to be recorded. In the variable-width method, the slit is illuminated with constant intensity but the length of the illuminated portion of the slit varies with the amplitude of the sound, thereby giving a sound track (Fig. 71) of variable width but constant exposure.

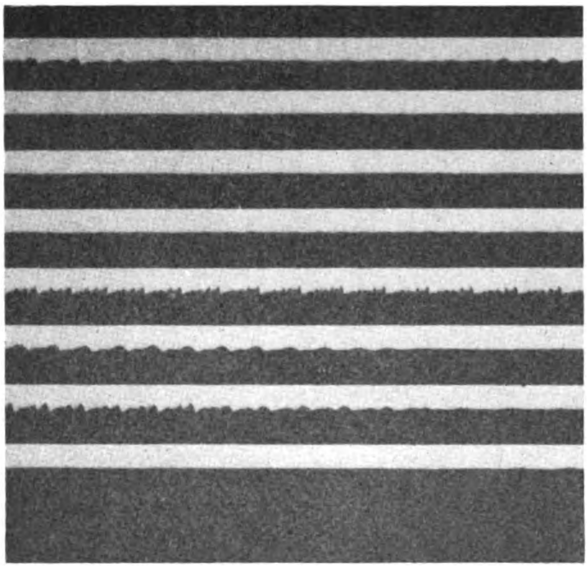


Fig. 71. Typical Sound Tracks on Film for Film Phonograph

An improved film phonograph of the variable-width type was developed by Dr. C. W. Hewlett, in which the light from a 50-watt incandescent lamp is utilized for recording. The light passes a straight-edge close to the lamp, is condensed and focused on the mirror of an ordinary oscillograph. The mirror in turn reflects the straight-edge diagonally on the physical slit and a microscopic objective focuses this slit on the film with ten-fold diminished linear dimensions.

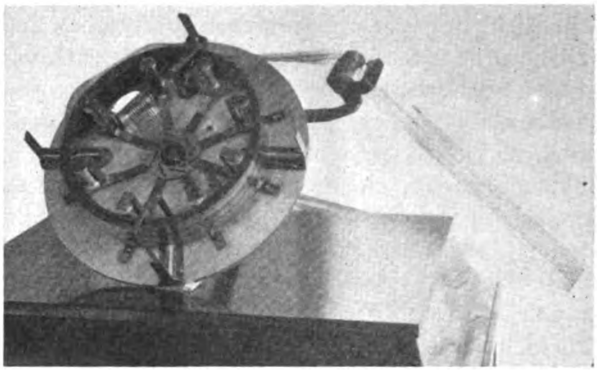


Fig. 72. Continuous Film and Electro-mechanical Device for Automatically Shifting the Sound Track

This machine at present records nine tracks on the film and a 400-ft. roll of film will hold a program of about 1 hr. and 20 min., but it is expected that, by increasing the number of tracks to fifteen, a record exceeding two hours can be made on this length of film.

In order to avoid the interruptions involved in reversing the direction of the film at the end of each successive sound track in reproducing, an ingenious mechanism has been devised (Fig. 72) whereby the ends of the film are sealed together to form a continuous band and run through the machine continuously in one direction. The shifting of the scanning light spot is accomplished electrically by means of a little metal tab on the edge of the film which serves to complete an electric circuit that moves the whole optical system a distance of 2.5 mm. from one sound track to the next. The shifting mechanism is actuated by an electromagnet to which current is supplied through the plate circuit of a thyratron in series with a thermal cut-out switch.

Cathode-ray Tube

Millions of sapphires are used each year as jewels for bearings in meters and other electrical instruments. Some of these jewels are natural and some are synthetic, and it is important to know which is which.

The difference can now be detected by means of the cathode-ray tube. Trays of unclassified sapphires being exposed to the rays (Fig. 73) for a few seconds in a dark room, all the stones, but one variety of natural sapphire, glow or radiate colors while exposed to the rays; when the rays are turned off the natural stones cannot be seen, whereas the synthetic stones continue to glow.

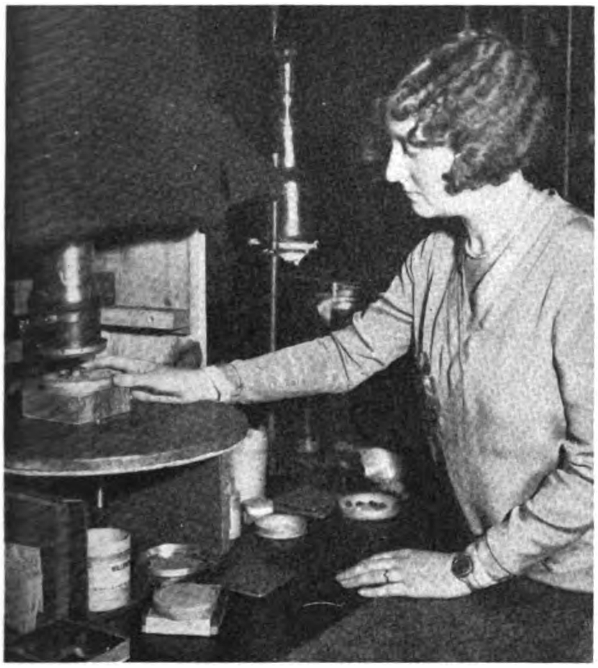


Fig. 73. Placing Rough Sapphires for Cathode-ray Exposure Test

This is the first commercial application of the cathode-ray tube.

Fused Quartz

The adoption of fused quartz windows for a large solarium necessitated the production of 1200 panes and resulted in an improved process of manufacture. The difficulty of making quartz windows can be appreciated when it is realized that the melting point of quartz approaches a temperature of 3200 deg. F., which is about three times that of glass, and that it is extremely viscous.

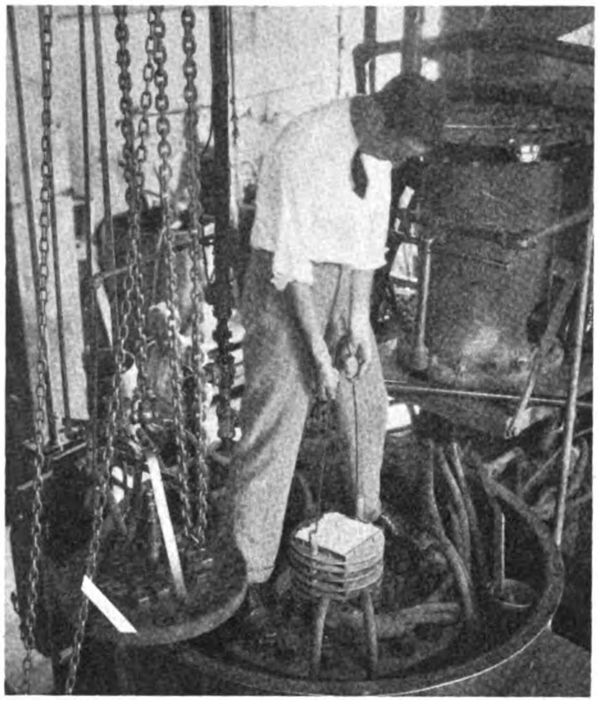


Fig. 74. Loading Furnace with Trays of Crystal Quartz for Making Clear Fused-quartz Windowpanes

Earlier methods for producing high-quality quartz window panes involved the fusing, in a vacuum, of specially selected and treated quartz crystals in a square fabricated graphite box, and pressing the fused mass of quartz at 1000 lb. per sq. in. while in the molten state. A block 8 by 5 by 5 in. was thus obtained which when cooled was sliced into sections ⅛ in. thick and each pane was then ground and polished by hand.

In the new process, quartz crystal, crushed to ¼-in. mesh, is fused in a vacuum on flat graphite disks between thin graphite slabs in the form of a square 7½ by 7½ in. A number of these trays are stacked in a form (Fig. 74) and placed in a high-temperature furnace. When the quartz is fused, nitrogen is admitted to the furnace at a pressure of 150 lb. per sq. in. to compress the bubbles and the resulting plates upon cooling require only squaring of the edges by grinding. The plates themselves are 7½ in. square by ¼ in. thick. This new method does away with the former cutting, grinding, and polishing of each pane.

RADIO

Transmitters

The recently developed line of hot-cathode mercury-vapor rectifying tubes has been applied generally to radio transmitters. The line includes tubes of various ratings from 0.6 to 20-amp. peak values of rectified current. The largest rectifier set so far constructed is designed to deliver 50 amp. at 15,000 volts, and the equipment is probably the largest high-voltage rectifier which has been produced commercially.

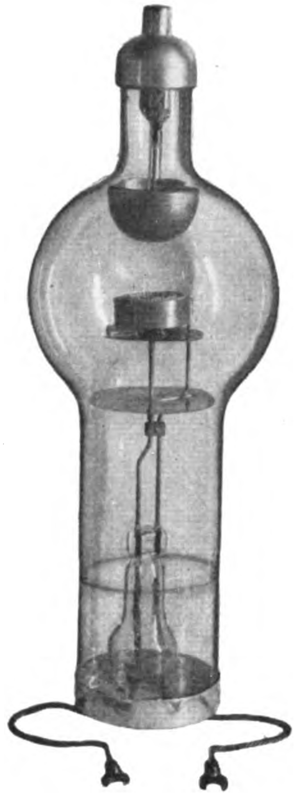


Fig. 75. Two-element Half-wave Hot-cathode Mercury-vapor Rectifier Tube

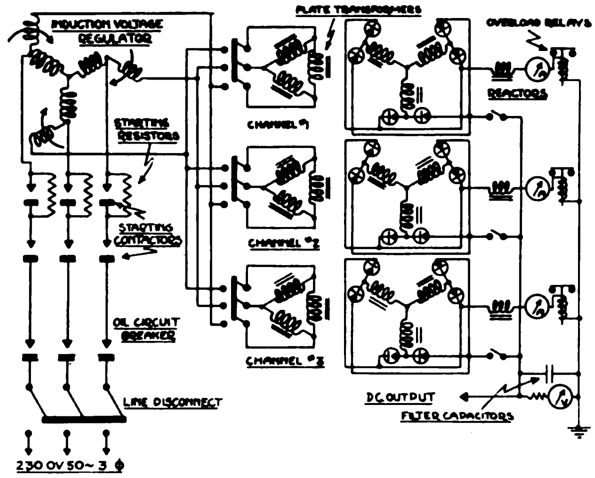

INDUCTION VOLTAGE REGULATOR
PLATE TRANSFORMERS
OVERLOAD RELAYS
REACTORS
STARTING RESISTORS
CHANNEL #1
CHANNEL #2
CHANNEL #3
STARTING CONTACTORS
OIL CIRCUIT BREAKER
LINE DISCONNECT
DC OUTPUT
FILTER CAPACITORS
2300 V 50~ 3 φ

Fig. 76. Circuit Diagram of Rectifier. Each channel employs a three-phase full-wave connection

The hot-cathode mercury-vapor rectifier tubes used have remarkable efficiency. The particular type employed in this rectifier (Fig. 75) is capable of passing 20 amp. with a potential drop of only 18 volts. The potential drop in the tube is practically independent of the current, and for this reason care must be exercised when operating such tubes in parallel to make certain that each tube carries its share of the load.

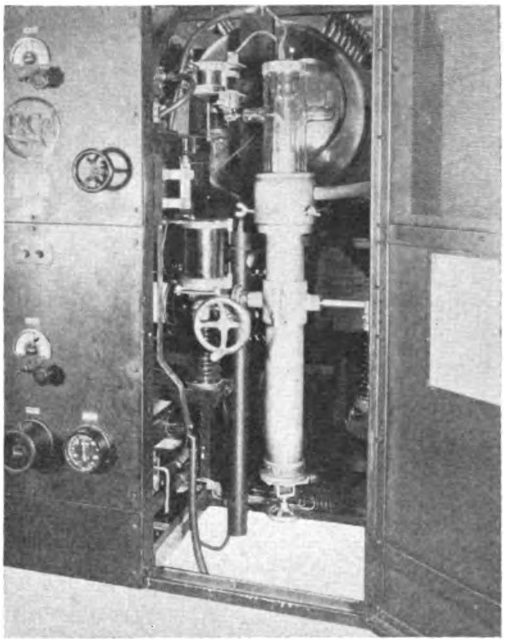


Fig. 77. 50-kw. Broadcasting Power Amplifier

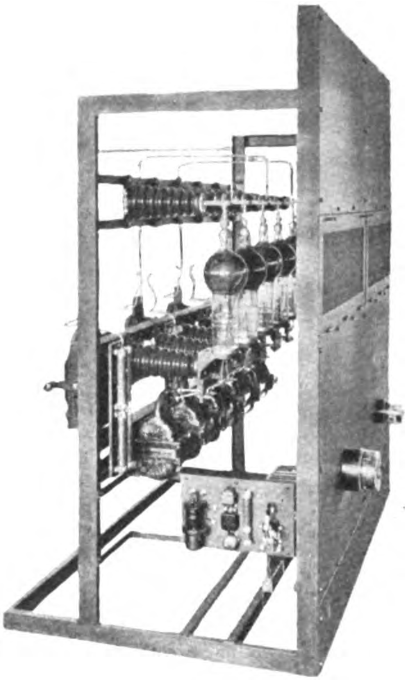


Fig. 78. Main-power Rectifier for 50-kw. Broadcasting Transmitter

A total of 18 of these tubes is used in the rectifier, arranged in three independent channels of six tubes each (Fig. 76). Each channel is provided with a separate surge reactor which serves the double purpose of keeping the load equalized among the three channels and of assisting in the reduction of the 300-cycle ripple inherent in this type of circuit. (The line frequency is 50 cycles.) A common high-voltage condenser bank completes the smoothing network, and results in a direct-current output having a ripple component of the order of 0.05 per cent.

The circuit used for each of the three channels is known as the "three-phase full-wave connection" and has a number of advantages over the well-known "double Y" and "triple T" circuits, commonly associated with high-voltage rectifier practice. Chief among these is the fact that no special design is necessary for the plate transformers. Rectification occurs during each half cycle of each phase and consequently there is no direct-current component in the windings. Since rectification takes place over both halves of the cycle, the transformer windings are utilized to practically the same extent as they would be under alternating-current load conditions.

This circuit has long been known to the art but was not used extensively until the advent of the mercury-vapor tube because of the regulation which would result if the conventional high-vacuum rectifier tube were used.

Any single channel can be used alone, or any two channels or all three may be used at once. The operating characteristics may be summarized as follows:

Input power: 2300 volts, 50 cycles, 3-phase delta.
Output power: 4000-15,000 volts d-c.; 0-50 amp. d-c.
Output ripple: Approximately 0.05 per cent.
Conversion efficiency at full load: 96 per cent.
Input power-factor: 92 per cent lagging.
Overall regulation from no load to full load: approximately 8.6 per cent.

Broadcasting

A new 50-kw. broadcasting transmitter incorporating modern features was constructed and placed in operation. By the system of linear amplification used, 100 per cent modulation is obtained; the output varying between 200 kw. and zero. Two tubes in the output circuit are operated on the push-pull principle (Fig. 77) and the high-voltage d-c. power supply (Fig. 78), normally operated at 18,000 volts, is obtained by mercury-vapor rectifier tubes. Improved frequency stability is obtained by modern methods in the utilization of quartz crystals, which determine the frequency of the emitted wave.

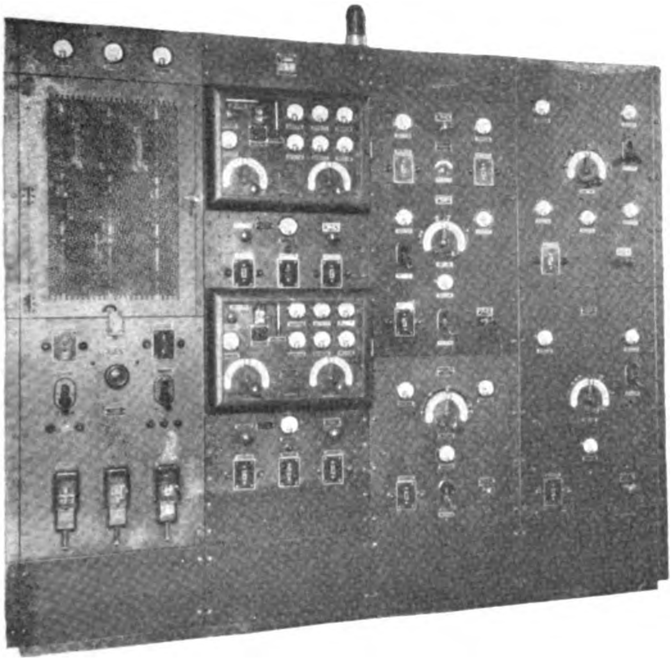


Fig. 79. 1-kw. Exciter Unit, Crystal Controlled for Short-wave Transmitter

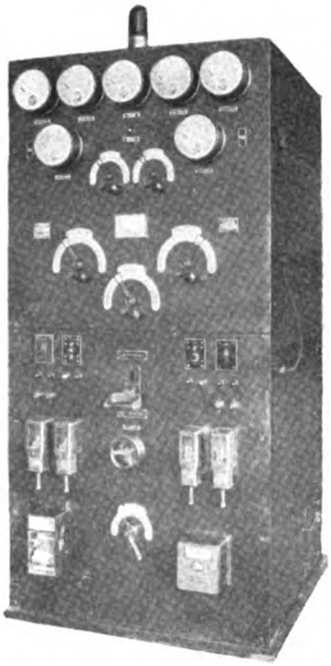


Fig. 80. Power Amplifier for 20/40-kw. Short-wave Transmitter

Communication

To fill the need for high-power short-wave transmitters for communication purposes, improved designs having an output of 20 kw. at 14 meters, increasing to 40 kw. at 42 meters, were constructed; provision being made to shift rapidly between any two wavelengths in the band. Each equipment consists of a crystal-controlled exciter (Fig. 79), a power amplifier (Fig. 80), and a rectifier. The methods adopted for mounting and operating the crystal result in considerably higher frequency precision and stability than were previously obtainable. Four water-cooled tubes are used in the power amplifier. Mercury-vapor rectifying tubes are used throughout the set; entirely excluding rotating machines.

Development of facsimile telegraphy for communication service, on the principles of picture transmission rather than Morse code, resulted in improved terminal apparatus; more extensive transmitting and receiving facilities at the Schenectady and California terminals of the developmental channel, and comprehensive data on propagation phenomena. Radio transmitters, receivers, and facsimile terminal equipment are now available for commercial use.

Airport Communication

Commercial aviation now receives weather reports and other data essential for safe navigation through the installation of a number of 2-kw. radio-telephone transmitters (Fig. 81) at many leading airports. A total of 47 of these transmitters will soon be in active service under the jurisdiction of the Department of Commerce, Airway Division, and seven were installed by the Transcontinental Air Transport Company. The equipment covers a frequency range of 100 kc. (3000 m.) to 550 kc. (545 m.) Continuous-wave and tone telegraphy are provided as well as telephony. The frequency band used for telephony is 300 kc. (1000 m.) to 350 kc. (850 m.). Provision is made for both local and remote control so that the operator need not be located near the transmitter.

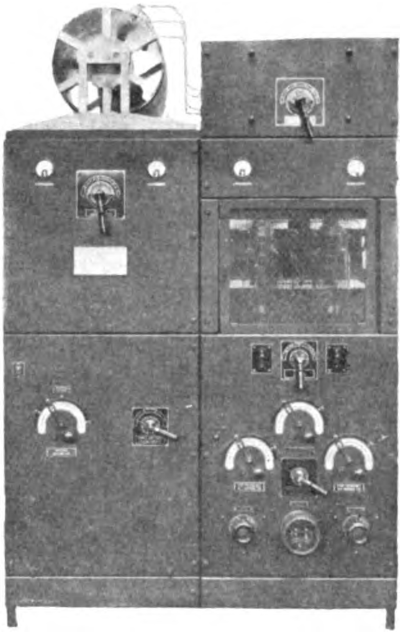


Fig. 81. 2-kw. Radio-telephone Transmitter Designed for Airport Communication

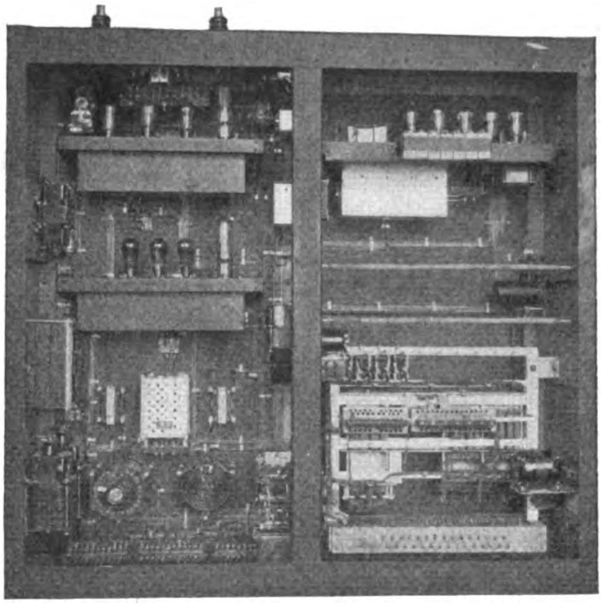


Fig. 82. Rear View of 50-watt Improved Type of Carrier-current Telephone Equipment

A short-wave receiver was produced for the reception of communication and broadcast signals covering a frequency range of 1200 kc. (250 m.) to 25,000 kc. (12 m.).

Developmental Station

The short-wave transmitters at this station have continued to render reliable service in transmitting direct accounts of important events in world history to foreign countries. Events in connection with the Round the World Flight of the Graf Zeppelin on three occasions were successfully broadcast through Station W2XK, 17,300 kc. (17.3 m.) to European stations, where the programs were rebroadcast. Stations W2XAF 9,530 kc. (31.4 m.) and W2XAC 8,650 kc. (34.7 m.) were used regularly for transmitting to Commander Byrd and his party at Little America. A special directive antenna is used in conjunction with this service to insure reception in this far-off region. The regular evening programs of WGY are also broadcast through stations W2XAF and W2XAD. Station W2XCW, 2,150 kc. (140 m.) was utilized in connection with the development of television.

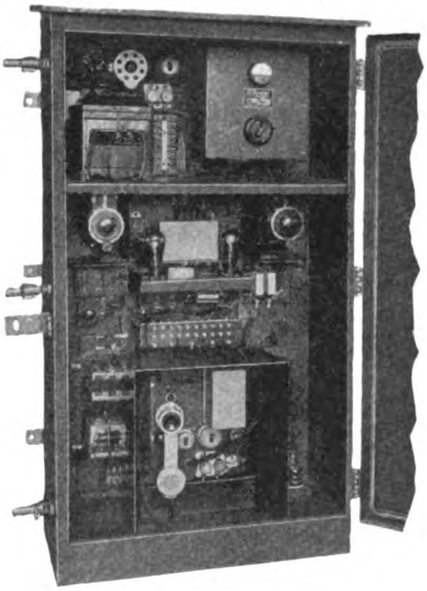


Fig. 83. Booth-type Low-power Carrier-current Telephone Equipment

CARRIER-CURRENT COMMUNICATION

Terminal equipment rated at 50 watts output (Fig. 82) incorporates a number of important improvements which mainly provide for increased flexibility in the transmission and reception of calls. By the use of a variable-band pass filter, a larger number of carrier channels on the same system or adjacent systems are possible without interference between channels.

A new low-power equipment (Fig. 83), known as the booth type, has already found wide application. The operation is simplex, the send-receive control being located on the combination telephone hand set in the form of a push button switch. Provision is made for selective transmission and reception of calls for intercommunication with all other types of G-E carrier-communication equipment. The power supply is normally from storage batteries but the set may be operated from dry cells, for intermittent service.

VACUUM TUBE APPLICATIONS

Thyratrons, the hot-cathode mercury-vapor tubes having a control element, are finding application to power circuits. By varying the phase of the voltage applied to the control element of these tubes in a rectifier circuit, the rectifier output may be controlled in a very efficient manner. Control equipment of this type (Fig. 84) was utilized for operating the lighting for the Chicago Civic Opera. The controlled output of the rectifier varies the saturation in an iron-core reactance, a secondary winding on this reactance being in series with the lights to be controlled. Absence of the inherent losses of resistance dimmer rheostats, which in the case of the Chicago Civic Opera installation would be large since the total controlled lamp load amounts to 1250 kw., and the provision for a flexible remote control are two outstanding advantages of this system.

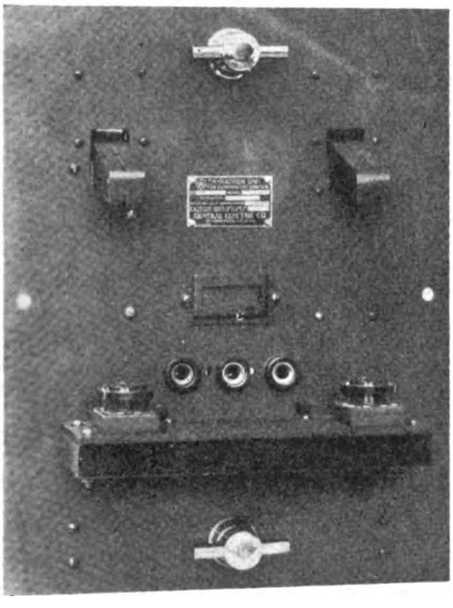


Fig. 84. Thyratron Unit for Dimming Control of Theater Lights

Photo-electric control units were designed to operate relays by changes in the intensity of light and may be applied to the control of street lights, airport beacons, sign lighting, and similar uses.

One application of this type consists of a box, about the size of an ordinary radio-receiving set. On one end is a lens (Fig. 85) which allows light from the outside of a building to fall upon a photo-electric tube which is adjusted for a certain degree of daylight intensity. Whenever the light from outside falls below this point, it causes a relay to switch on the electric lights in the building. The operation is reversed and the lights switched off when the natural illumination is sufficient to meet the requirements.

At the exit end of one of the two-mile tubes of the Holland tunnel under the Hudson River, a photo-electric tube is utilized to count the number of vehicles that pass, and the count is registered on a dial located in the administration building.

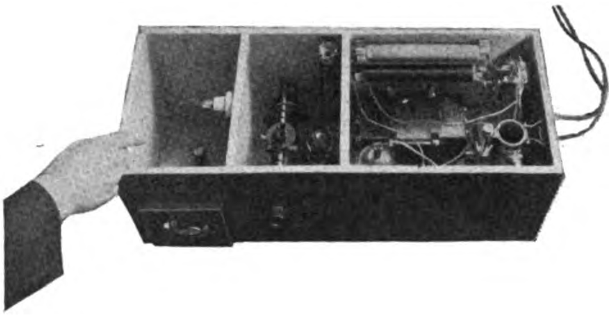


Fig. 85. Photo-electric Equipment for the Automatic Control of Lighting Systems

The apparatus used consists of a small floodlight mounted in an inclined position and projecting a slender beam of light upon a circular window in a box placed beneath the sidewalk at the opposite side of the roadway. The box contains a photo-electric tube, an amplifying tube, and an electrical relay.

Every time a vehicle passes the spot (Fig. 86), the beam of light falling upon the photo-electric tube through the window is interrupted, affecting the photo-electric tube so that a slight electrical impulse is created. This is amplified by the vacuum tube and fed to the relay. The latter energizes a transmission circuit, the other end of which is in the administration building where a registering dial is actuated by the electric current so that it turns, in response to each impulse from the relay.

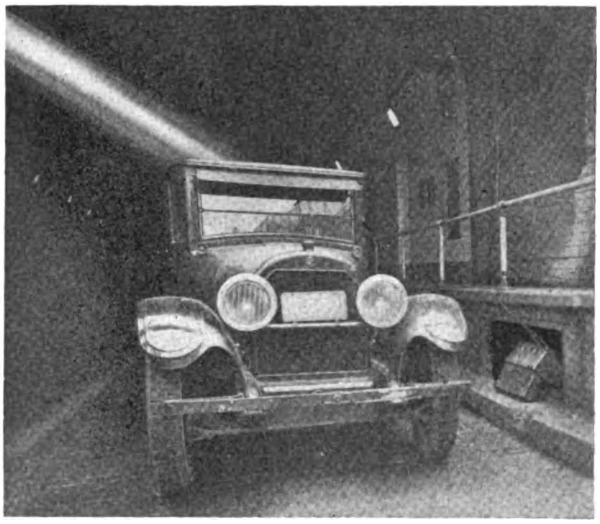


Fig. 86. View in Holland Tunnel, Showing Operation of Photo-electric Counting Device

TRANSFORMERS

One of the outstanding accomplishments, in transformer design and manufacture, was the development of the non-resonating type of transformer.

In any ordinary transformer, voltages due to lightning, or to high-frequency oscillations caused by switching or arcing grounds, are not distributed uniformly throughout the winding; and frequently very high voltages are concentrated across a small proportion of the winding by reason of the impact of a steep-front wave, or by oscillations resulting there from, and from high-frequency oscillations imposed on the transformer.

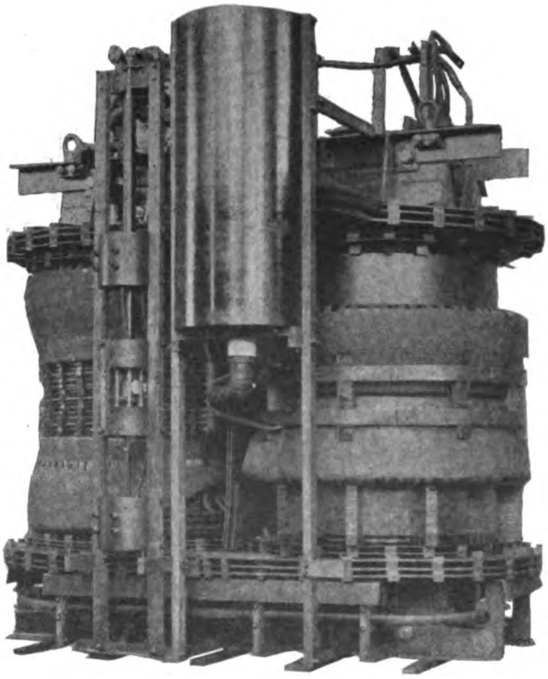


Fig. 87. Typical Construction of Non-resonating Type Transformer Rated 28,866-kv-a. 220-kv. High-voltage Side

The order of magnitude of the most severe lightning voltages is limited by the break-down value of line insulation, bushings, or protective apparatus. It may be expected to be of the order of 10 to 15 times the normal voltage to ground; while switching surges may reach a maximum of 5 to 7 times normal, but in the ordinary transformer the effect of switching surges, if of the frequency that will cause resonance, may give about the same maximum internal voltage stresses as those caused by lightning.

The rea on why voltage distribution in the ordinary transformer is not uniform, and oscillations are set up, is that individual elements in the winding, such as coils and turns, have capacity to ground, and the capacitance charging current has to flow through the inductance of portions of the winding.

Since the charging current increases with the steepness of the wave front, or with increase of frequency, and the voltage drop across the inductance of the coils also increases, the voltage drop across various elements of the winding changes with the frequency or the steepness of the wave front.

In the non-resonating type of transformer, the capacitance charging currents of the various elements of the winding to ground are supplied by means exterior to the winding, *i.e.*, by metallic shields placed outside of the coils. Therefore no charging current, from the coils to ground, passes through the inductance of the coils, so that the voltage drop across any of the coils is a constant, independent of frequency.

Another way of describing the non-resonating feature is to say that each coil and turn is so located between the shields and ground that its voltage, obtained by its position in the dielectric field between shields, is exactly the same proportion of the terminal voltage as that induced in those parts under normal-frequency voltage.

Since the voltage distribution is uniform in the non-resonating transformers, irrespective of frequency of applied voltage, no oscillation can occur, and each portion of the winding takes the proper proportion of the stress between the terminals. This results in a very high factor of safety, since the stresses between turns may be reduced as much as 50:1, compared to those in the ordinary transformer.

The stresses between coils, and from windings to ground, are also greatly reduced. While the non-resonating type of transformer is applicable to any voltage circuit, it is at present only economical for

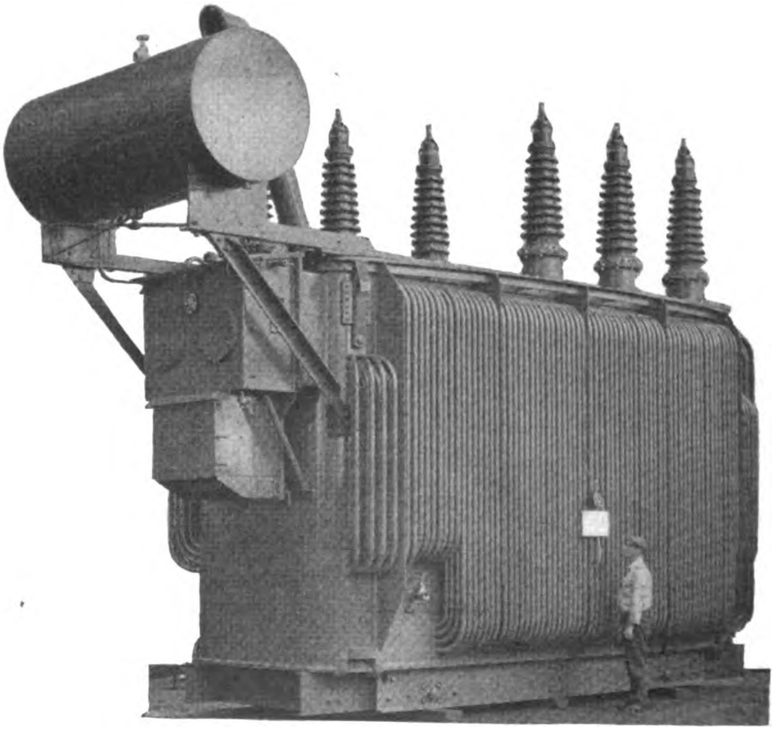


Fig. 88. 45,000-kv-a. 3-phase Transformer Equipped with Load-ratio Control

high-voltage transformers (Fig. 87), and finds its greatest application on 220-kv. systems where the problem of insulating transformers against transient voltage is the most difficult.

There are already in service a total of twenty-one units, totaling more than 484,000 kv-a., of this type, and forty-eight units, aggregating 928,000 kv-a. are under construction.

Among these are three 40,000-kv-a. 50-cycle 220-kv. transformers for the Southern California Edison Company. These are large-capacity single-phase units, designed with partially tapered insulation from the line terminal to neutral. The neutral is designed to be grounded through an impedance which will reduce the current flowing to ground in case of a line fault, but will limit the dynamic voltage rise from neutral to ground to 73 kv.

Another unusual group consists of fourteen 13,000-kv-a. 220-kv. and seven 23,000-kv-a. 220-kv. transformers for the Fifteen Mile Falls Development of the New England Power Company. This will be the first 220-kv. transformer system in the New England States. In order to reduce lightning voltages imposed on the lines, they were designed with minimum height of towers and flat spacing of the wires, each tower being protected with two ground wires.

Four 25,000-kv-a. 50-cycle 220-kv. to 72-kv. non-resonating type transformers for the Southern California Edison Company were equipped with load-ratio control in the 72-kv. winding. They were shipped complete in their own tanks, with the load-ratio control mechanism attached.

Three 28,866-kv-a. transformers of this type, for the Pennsylvania Power and Light Company, were provided with extra insulation on account of their being used on a transmission line of more than normal insulation for a 220-kv. circuit. They were tested at 500,000 volts.

Load-Ratio Control

Power transformers with voltage taps so arranged as to permit their change under sustained load, a method which has become known as transformer Load-Ratio Control, have found continued application to the extent that of all the power transformers in excess of 500 kv-a. shipped during 1929, 25 per cent, by kv-a., were so equipped. Up to the middle of November there had been completed or were under construction during the year approximately one hundred units aggregating 1,180,000 kv-a. controlled output.

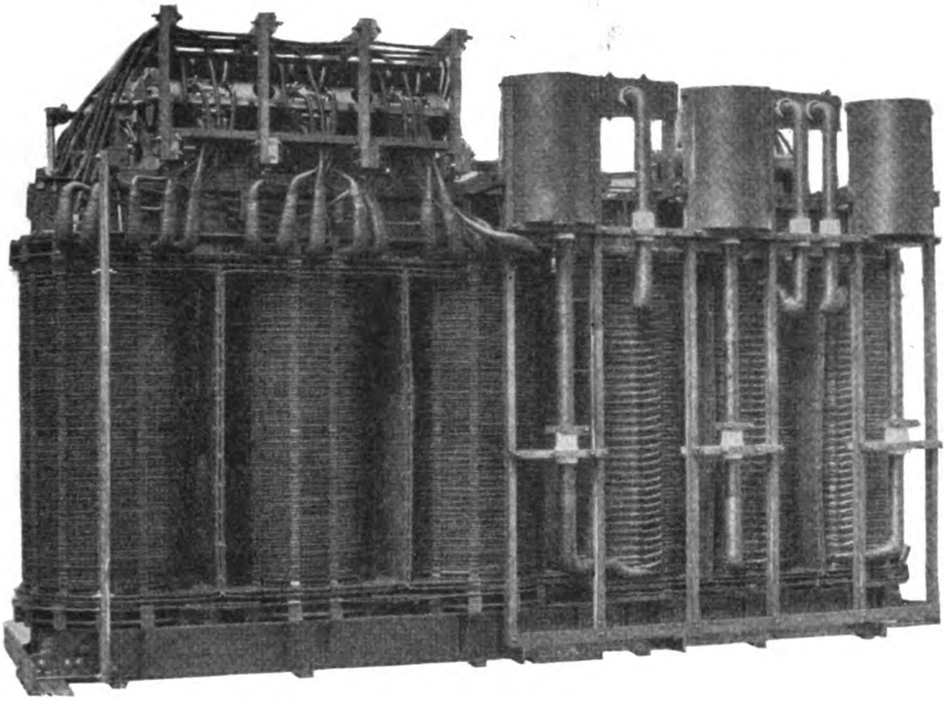


Fig. 89. Internal View of 45,000-kv-a. 3-phase Transformer Showing Regulating Unit at Left and Series Unit at Right

Among the most outstanding machines built was one three-phase transformer of 45,000-kv-a. output (Figs. 88 and 89) weighing 114 tons complete and ready for service; and six single-phase 20,000-kv-a. transformers, each equipped with *two* load-ratio controls for the independent regulation of a double secondary winding.

There are now installed or in process of manufacture a total of about 3½ million kv-a. of G-E load-ratio control transformers.

To enlarge the field of application of load-ratio control equipments, a new type was developed capable of handling currents up to 2000 amp. This required the design of a 2000-amp. ratio adjuster and a 2000-amp. contactor (Fig. 90).

The inherent advantages in changing the transformation ratio under sustained load were at first taken advantage of only on large transformers, and all necessary component parts like ratio adjusters, contactors, etc. were laid out accordingly for heavy currents and high potentials. As the benefits of load-ratio control, compared with other known methods of alternating-current regulation, became more widely known, however, a demand arose for the application of this method to smaller transformers.

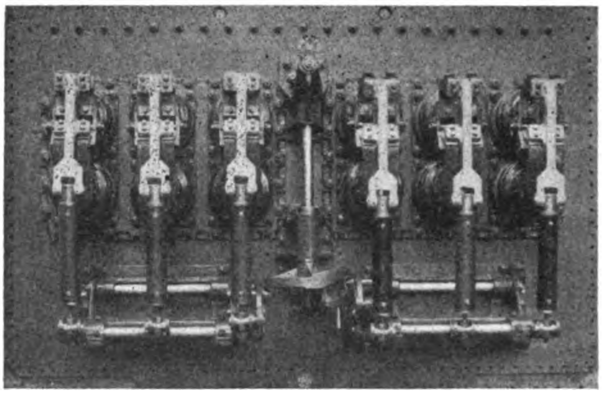


Fig. 90. 2000-amp. 3-phase Contactor for Load-ratio Control Transformers with Oil Tank Removed

The use of 1000-amp. apparatus for circuits demanding only a maximum of one-half of that current was obviously uneconomic, and an entirely new line of load-ratio control equipment was designed for currents not in excess of 400 amp. and circuits of 15 kv.

In general, when two generating stations are interconnected for an exchange of power, the voltage at each station is fixed because of the requirements of local distribution. Therefore, if the amount of load to be exchanged is variable, a variable-ratio transformer should be interposed otherwise wattless current will circulate between the two stations. This has been one of the chief uses for load-ratio control transformers. Usually the voltage ratio is adjusted so that the wattless current transmitted over the interconnecting line is as near zero as possible.

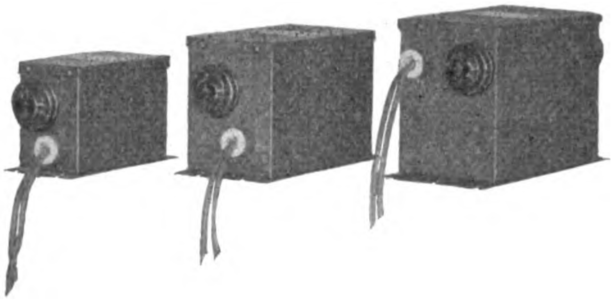


Fig. 91. Standard Line of Sign Lighting Transformers for Neon Glow-tube signs

The amount and direction of power exchange is determined by the phase angle between the two generating stations and this is controlled by the respective governor settings. Occasionally, due to other interconnections, it is impossible to vary the phase angles of the generators and then the amount of power that can be transmitted over a given interconnection is virtually fixed unless other means of shifting the phase angle can be supplied. The load-ratio control transformer connected for quadrature phase-angle control supplies a convenient means of accomplishing this result.

The Texas Power & Light Company will utilize for this service two unusual load-ratio control regulating transformers which are interchangeable. The series winding of each transformer has two coils which may be connected in series to give a 10 per cent in-phase buck or boost to the voltage in a 69,000-volt 20,000-kv-a. circuit and when connected in multiple will give a 5 per cent in-phase buck or boost to the voltage in a 69,000-volt 40,000-kv-a. circuit. In addition, each transformer will give a similar quadrature voltage control by means of suitable terminal-board connections. The two transformers may also be connected in series so that one will give in-phase voltage control and the other quadrature voltage control.

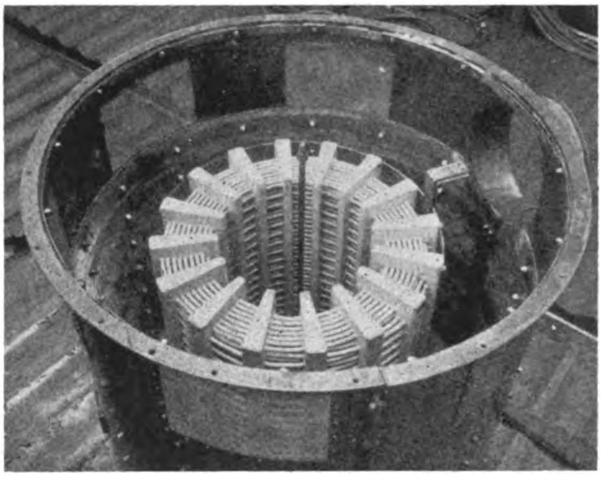


Fig. 92. Arrangement of Cast-in Concrete Reactor in Steel Housing

Except for the internal connections there is no difference between in-phase and quadrature voltage control. In fact, both may be placed in one unit simultaneously with separate switchboard control for each.

Oil Air-Pressure Cooled Units

The oil air-pressure system of cooling transformers was during the year applied to transformers aggregating about one million kv-a. in capacity. The largest units so far constructed in the United States are rated single phase, 40,000 kv-a., 220,000 volts, but these will be exceeded by four 60,000-kv-a. 132,000-volt units now under construction in England.

Refinements in design have resulted in an appreciable reduction in the amount of power required for the cooling system; and while this is of relatively small value in individual units, the widespread application of this method results in a very considerable aggregate saving.

Rectifier Transformers

Increases in the size of power rectifiers involved the construction of larger rectifier transformers. Whereas in 1928, the maximum capacity did not exceed 1500 kw. at 1500 volts, the maximum rating during 1929 was increased by the successive construction of units of 3000 kw. 625 volts, 3000 kw., 3000 volts, and 6500 kw., 650 volts; all these transformers being 12-phase units for 12- or 24-anode rectifiers.

In connection with the use of rectifiers for railway power service, transformers were designed for compounding to give normal voltage from no load to 150 per cent load. This required the development of a new method of compounding which consists of a special arrangement of reactors and capacitors in the interphase circuit of the rectifier. In addition to giving these desirable voltage characteristics, the new method of compounding causes the rectifier to function at unity power-factor at normal load, whereas on ordinary rectifier equipments the power-factor ranges from 90 to 95 per cent.

Sign-Lighting Transformers

Because of the increasing popularity of the neon glow-tube signs and the expansion of their use not only in large outdoor signs but also in the small indoor window signs, and special applications, there arose a demand for a greater range of sizes in sign-lighting transformers.

A new standard line of these transformers (Fig. 91) was produced which includes 12 different electrical output ratings ranging from 3500 volts open circuit, 18 m.a. short circuit, to 15,000 volts open circuit and 30 m.a. short circuit.

These transformers are so designed as to have a narrow width in order that they may fit into small narrow signs and between building walls. Four different sizes are included in the new line, and the same mechanical parts are adapted to several different electrical ratings.

REACTORS

The first air-cooled current-limiting reactors operating in steel housings without the use of oil were designed to meet underwriter's requirements where oil-immersed reactors could not be used. Standard cast-in concrete reactors were supplied with steel housings (Fig. 92) and natural ventilation is obtained through screened openings (Fig. 93) at the top, sides, and bottom.

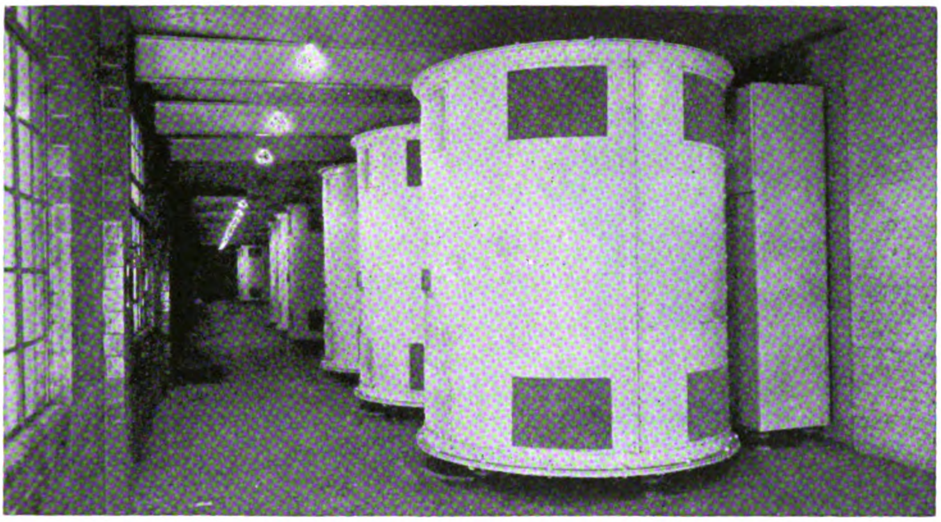


Fig. 93. Bus Sectionalizing Reactors Installed in Steel Housings. Ventilation is provided by the screened openings

The reactors are for use in sectionalizing a metal-clad bus and the metal housing entirely surrounds each phase of the bus so that no injury to the bus equipment can occur, except to the housing. The reactor housings are bolted to the bus housing and thus carry out a consistent scheme of phase isolation.

The bus and reactor housings are insulated from ground and are connected to the ground bus at suitable points, the insulation of the reactor housings being accomplished by supporting them on porcelain insulators. With this construction the only failure of the bus system that can occur is a failure to the housings and the current is carried by means of the ground buses in a definite route back to the generator neutrals. The steel housing eliminates the necessity for the concrete compartments in which reactors are usually installed.

The reactors are rated 2500 kv-a., 1385 volts, 1800 amp., 60 cycles and introduce 10 per cent reactance between 75,000-kv-a. sections of a 24,000-volt bus system.

Reactors with iron cores (Fig. 94) were supplied for use in dimming theatre lights. In addition to the usual alternating-current winding they have a direct-current winding. The alternating-current winding is connected in series with the lamps which are lighted by alternating current.

When full brilliancy is required, full direct current is supplied and this causes the core to be saturated with direct-current flux thus reducing the reactance introduced by the reactor sufficiently to allow full alternating-current to flow through the lamps.

When it is desired to dim the lamps, the direct current is reduced, thereby increasing the impedance of the reactor and causing a reduction of the current in the lamps and a consequent reduction in their brilliancy. By this control of the reactance a very gradual dimming of the lamps from full brilliancy to zero is obtained.

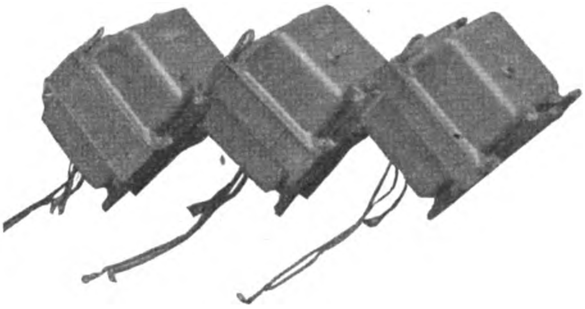


Fig. 94. Air-insulated Saturable-core Reactors for 115-volt Circuits

HIGH-TENSION CABLE

The first commercial installations of 132,000-volt oil-filled underground cable, which doubled the previous record for underground transmission voltage, have been entirely successful.

As a result, the New York Edison-United Company, with a 12-mile circuit in operation since August, 1927, added another line of equal length; and the Commonwealth Edison Company's installation, a 6-mile circuit completed in June, 1927, was also extended during the year.

Pressure Reservoirs

Cyclic changes in load and seasonal temperature, which cause expansion and contraction, are the principal causes of formation of voids in insulated cables. If these voids become ionized under voltage stress, the insulation is damaged and eventually the cable fails.

When cable joints are filled with a thin, penetrating oil and are connected to an external supply of excess oil (Fig. 95), the oil will migrate into the cable, tending to fill the voids and thus prevent deterioration of the insulation because of ionization. To be effective in filling these voids, the supply reservoir should furnish pressure to force oil into the cable when it is cooling and should receive oil from the cable when it is heating.

An oil-pressure reservoir designed for this purpose consists of a galvanized-metal tank inside of which are tight gas-filled metallic cells (Fig. 96) with flexible corrugated walls. When the cable heats, the oil in the cable expands and is forced out into the reservoir. This compresses the gas in the cells and builds up a pressure. As the cable cools, the oil in the cable contracts and the oil in the reservoir is forced out into the cable by the pressure built up during the heating cycle. Thus, the reservoir tends to keep the oil in the system under pressure at all times.

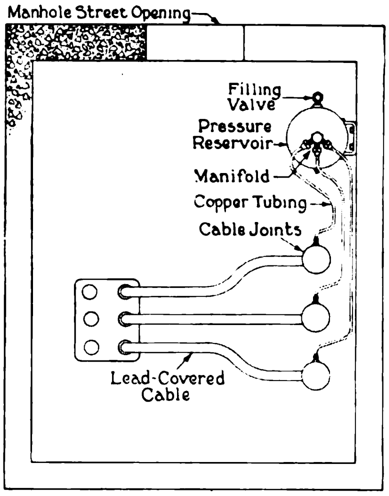


Fig. 95. Diagram Showing Relative Positions of Conductor Cable and Oil-pressure Reservoir

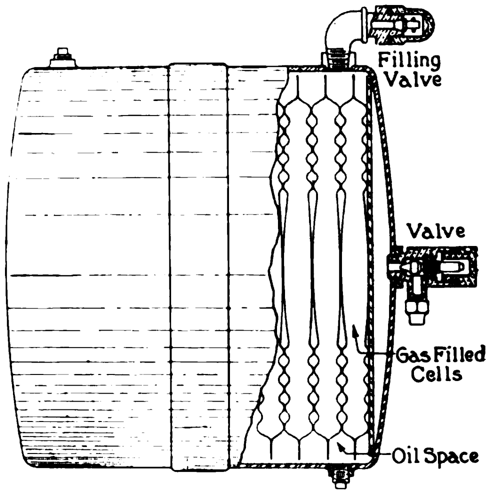


Fig. 96. Cut-away Section of Oil-pressure Reservoir, Showing Arrangement of Gas-filled Metallic Cells

The gas in the cells is not in contact with the oil and, therefore, there can be no loss of reservoir pressure because of reduction of the working volume of the gas through absorption in the oil, which would occur if the gas were in contact with the oil. Gas absorbed by the oil would be carried into the cable by the oil and might be liberated and ionized, causing damage to the insulation with subsequent failure.

AUTOMATIC STATIONS

Hydroelectric

The Wisconsin Power & Light Company of Madison (Wis.) placed in service a waterwheel-driven generator of 2400 volts, 350 kv-a., which uses a fast and accurate new method of speed control for synchronizing. This control is adapted to be used with the standard governor synchronizing motor.

A greatly-improved speed-limit device (Fig. 97) has a wider range than the previous design. A removable cover facilitates maintenance and inspection, and the device is particularly adapted to low-speed machines. It can be mounted horizontally or vertically.

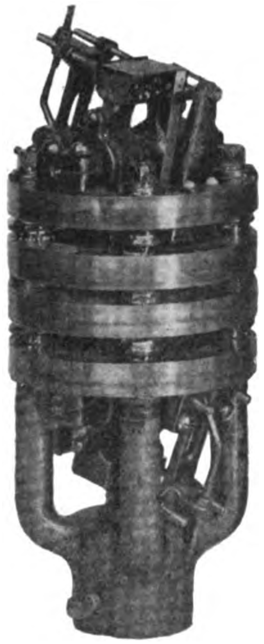


Fig. 97. Speed-limit Device for Waterwheel-driven Generators

Railway Signal and Train Control

In addition to the 3000-volt d-c. substation and track feeder equipment installed by the Cleveland Union Terminals Co., there were placed in service three 4400-volt signal feeders. An interesting feature in connection with this service was the use of a new type of oil-immersed latched-in contactor.

Synchronous Condensers

Two large synchronous-condenser equipments were installed by the Pittsburgh Plate Glass Company. Each consisted of a 5000-kv-a. unit with a direct-connected 600-kw. generator, a 35-kw. generator for mill-motor control power, and an exciter. The stored energy in the condenser rotor maintains d-c. service during a-c. interruptions of several seconds' duration.

Mining Substations

Of particular value in the mining field is an equipment of modified design which separates the high-voltage apparatus from the control panels. At the same time, a very compact arrangement of devices is secured, making the equipment particularly adapted to locations where floor space is limited.

The starting and running contactor, which in itself is very compact, is mounted in an angle-iron framework (Fig. 98) together with the oil circuit breaker, current transformers, and potential transformer. The starting auto-transformer is mounted on the top of the same frame. Despite the very compact arrangement of switching equipment in this framework, all of the component parts are readily accessible for inspection and maintenance.

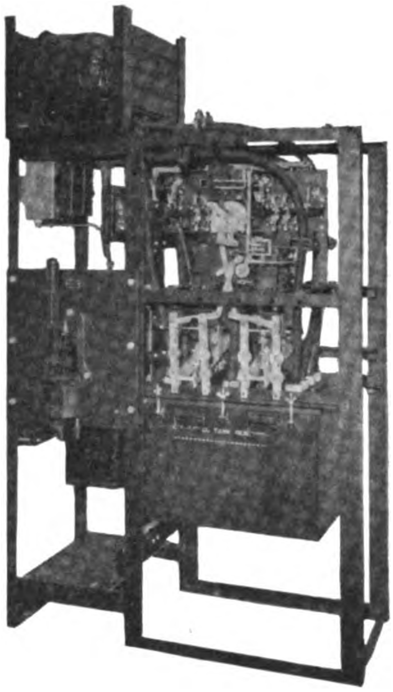


Fig. 98. Automatic Switching Equipment for 275-volt Mining Synchronous Motor-generator Set

The Butler Consolidated Coal Company, Butler (Pa.) placed in service two unique equipments (Fig. 99) each of which consisted of control panels and a starting and running unit for a 300-kw. 250/275-volt motor-generator. These units were each mounted on wheels for moving to various locations in the mine and were particularly adapted to low head-room requirements.

Automatic mine pumping units were a feature of extensive outdoor switching equipment placed in service by the Philadelphia and Reading Coal and Iron Company.

Preferred-emergency Equipment

To meet the demand for a simple preferred-emergency throw-over equipment of moderate capacity, a unit was developed (Fig. 100) consisting of a double-throw oil circuit breaker operated by a cam mechanism. This was mounted on the back of a panel carrying the necessary control devices. For use on circuits having non-synchronous sources, this equipment has a maximum capacity of 400 amp. at 4500 volts.

D-c. Reclosing Feeders

Feeder equipments for 250 volts are usually for industrial service. Several of this type were installed by the Pittsburgh Plate Glass Company and are of particular interest. A feature is the reclosing without "feeling out," if the rotating machinery maintains voltage on the feeder, thus decreasing the time of interruptions to a minimum. In this manner, costly stopping of some of the rotating machinery is avoided when momentary overload occurs.

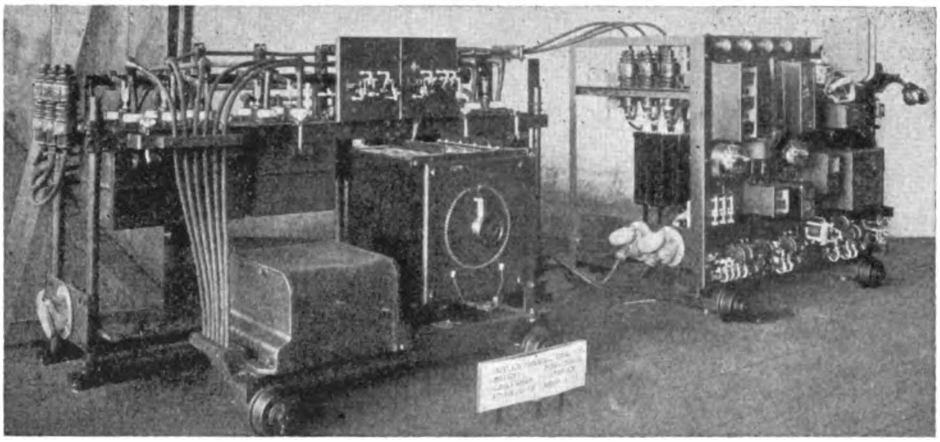


Fig. 99. Portable Automatic-switching Equipment for 275-volt Mining Synchronous Motor-generator Set

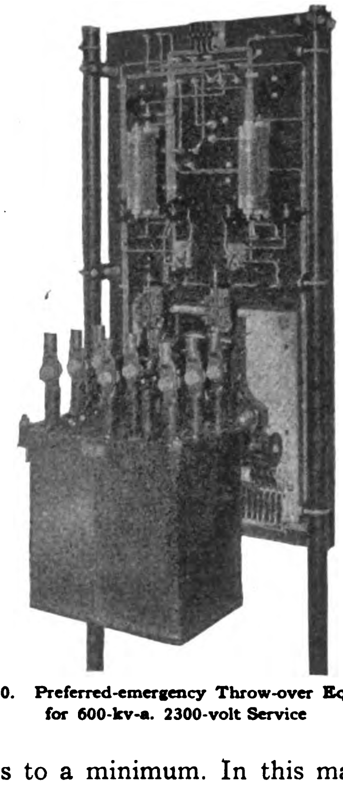


Fig. 100. Preferred-emergency Throw-over Equipment for 600-kv-a. 2300-volt Service

The capacities of d-c. reclosing feeder equipments for mining service have been extended to 2500 amp. with panel-mounted circuit-interrupting device.

Supervisory Equipment

A new feature in synchronous selector supervisory equipment provides indication of oil circuit breaker positions at a central point without control. An installation of this type is being made for the New York Edison Company and will indicate 138 breakers in the Hell Gate Station to the system operator at Waterside over four wires leased from the telephone company. The equipment will indicate breaker positions at the rate of 20 per sec.

It is significant that in several recent installations of automatic-switching equipment for railway service some form of synchronous selector supervisory apparatus has been considered essential. In conjunction with the equipment for the New York Board of Transportation, synchronous selector supervisory apparatus will be used for exercising control over nine outlying stations and 25 track zones. Automatic telemetering will provide for reading at a central point the individual and total input for six automatic substations.

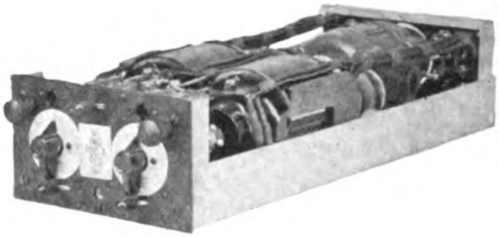


Fig. 101. Individual Control Unit Selsyn Thyratron System

Selsyn Thyratron System

The new type of theatre lighting control equipment installed by the Chicago Civic Opera Company included a self-synchronous motion-transmitting or Selsyn control unit (Fig. 101) mounted on a pilot board with which the operator obtains the desired lighting effects. The Selsyn unit gives simultaneous control of two or more circuits. This equipment controls 147 separate circuits.

Totalizing Equipment

Automatic-totalizing equipment was developed to the point of commercial application. This equipment, by electrical means, quickly and accurately totalizes units of several different numerical values. These totals can be indicated in several places, either by large or small indicators.

Suppose for example it is desired to use this equipment in connection with the sale of tickets having four different numerical values from perhaps 50 different ticket windows. Let it be assumed that these values are 2, 5, 10, and 50. It is evident that the sales from different windows may occur either successively or simultaneously. The totalizing equipment automatically takes care of the simultaneous sale of tickets and correctly totals all sales.

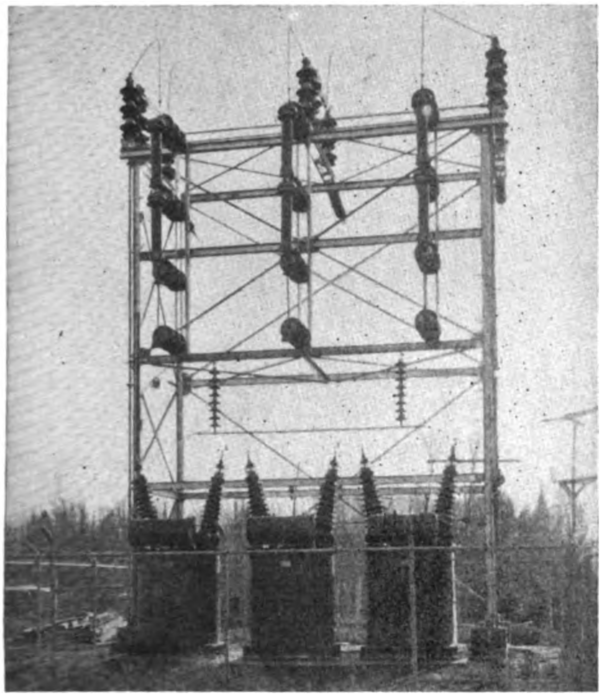


Fig. 102. Three-phase Delta-connected High-voltage Rural Substation Equipment for Supplying 2300-volt Service Direct from 110,000-volt Transmission Line

In addition to its application to ticket selling, this equipment can be used for the totalization of electric power demand originating from a large number of sources.

SMALL-CAPACITY HIGH-VOLTAGE SUBSTATIONS FOR RURAL SERVICE

In order to provide electrical service for rural communities directly from 110,000-volt transmission lines at a reasonable cost, single-phase and three-phase small-capacity substations for this voltage have been added to the existing 66-kv. equipments.

Single-phase substations have been designed for operation on three-phase solidly-grounded neutral systems, and the three-phase substations have been designed for operation on either grounded or ungrounded systems.

Fig. 102 shows a three-phase 150-kv-a. 110,000-volt substation with three 50-kv-a. single-phase transformers having the high-voltage windings connected in closed delta.

These complete substations are designed and built as a unit, having the insulation throughout coördinated with the insulation of the transmission line to which the substation will be connected, and the over-current protection on the high-voltage side coördinated with the over-current protection on the low-voltage side. The over-current protection on the high-voltage side consists of a specially designed fusible cutout in series with a current-limiting resistor to limit the maximum short-circuit current in case of a fault.

A horn-gap type of disconnecting switch mounted on top of the tower and operated by a handle near the base of the structure is provided for disconnecting the substation from the transmission line.

OUTDOOR SWITCHING EQUIPMENT

The growth in size of transmission and distribution systems and the corresponding increase in the required size of outdoor switching equipment (Fig. 103) has served to concentrate developmental work on both the mechanical structure and the electrical apparatus used in these stations with the idea of effecting as much reduction in their cost as could be secured without jeopardizing the vital factor of reliable performance. Many of the improvements made are of detailed character, but the economic results obtained have fully justified the effort expended on them.

A new type of group-operated horizontal-break disconnecting switch was produced in ratings of 88 to 154 kv. inclusive, which is particularly applicable to isolating service.

Another new group-operated switch, which is made in one rating of 15,000 volts, 200 amp. (Fig. 104), is a moderate-duty tilting-insulator horn-gap type of vertical-break design and was designed primarily for service on rural lines and low-capacity distribution systems.

The operation of this switch can be performed either manually or by means of a motor mechanism consisting of a motor-driven gear-reduction, opening and closing contactor, mechanical brake, and the necessary auxiliary switches, all enclosed in a fabricated-steel weather-proof housing. The motors are designed for operation at 110 and 220 volts, alternating current, and 115 and 230 volts direct current. Through a flexible coupling and gear reduction they are connected to an operating crank which rotates in the same direction for both the opening and the closing of the switch.

An over-insulated horn-gap type switch of unusually heavy construction was designed for use particularly on 66-kv. systems.

A line of current-limiting resistors in ratings up to 73,000 volts permits the application of a fuse in combination with the resistor on the primary of the potential transformers on systems where the possible short-circuit can exceed the fuse-interrupting capacity.

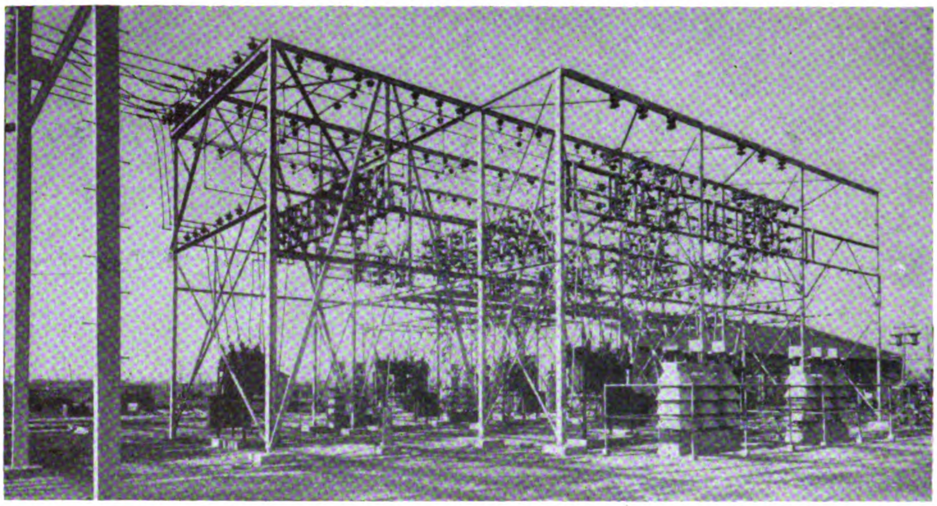


Fig. 103. Outdoor Switching Equipment for 66,000/23,000-volt 10,000-kv-a. System, Showing 23,000-volt Structure

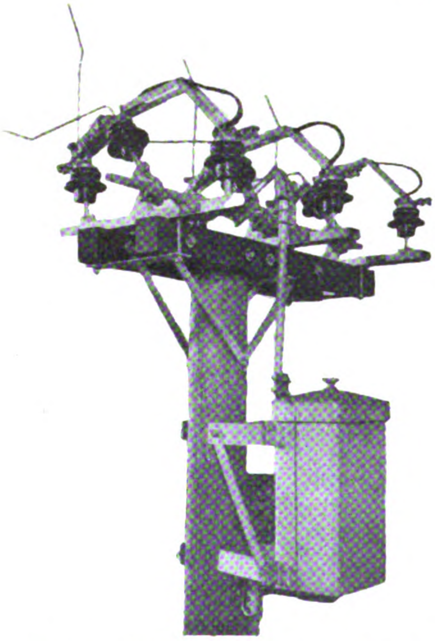


Fig. 104. Tilting-insulator Horn-gap Type Vertical-break Switch for Outdoor Service

The function of the resistor (Fig. 105) is to limit the amount of current which can flow into a fault, so that it will be kept well within the interrupting capacity of the fuse.

SWITCH GEAR

Metal Panels

Although the employment of steel for switchboard panels is not new, a number of improvements in design were made. A very compact arrangement was secured by placing the panels back to back with approximately 20 in. between them. Access to the interior of the structure is secured by hinging the rear panels (Fig. 106), the surfaces of which are used for mounting maintenance equipment.

Steel bench-board construction (Fig. 107) was utilized for a particular type of control board in the steel industry. It gives the operator clear vision over the top of the bench and the necessary instruments can be read while manipulating the control levers mounted on the bench. Two installations were made, one for the control of a 6600-volt mill motor and a 600-volt motor-generator, and another for controlling a 2500-kw. 250-volt motor-generator and eleven direct-current motors.

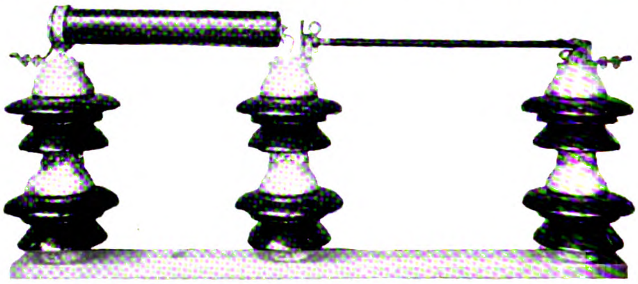


Fig. 105. Outdoor Switching Equipment Combining Expulsion, Fusible Cutout, and Disconnecting Switch with Resistor

A number of metal-panel units for synchronous-motor control were installed side by side, forming a totally enclosed structure accessible at the rear by means of swinging doors. This type of construction is also applicable to feeder service where moderate capacities and voltages are involved.

Metal Clad

A large increase in the use of indoor metal-clad gear (Fig. 108) took place during the year. As before, the air-insulated type has been most popular, but a number of oil-filled designs were built. These oil-filled equipments were used in locations such as steel mills, when dust-tight requirements had to be met.

Of particular interest is a panel section for relaying. The panel carries five three-phase relays with current indicators as part of the metal-clad structure.

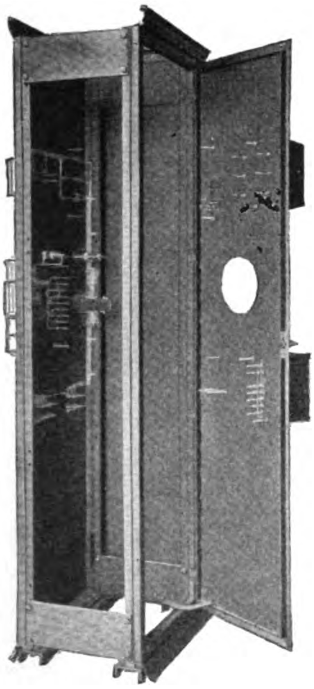


Fig. 106. Steel Switchboard Panel, Showing Arrangement of Door for Access to Rear of Panels

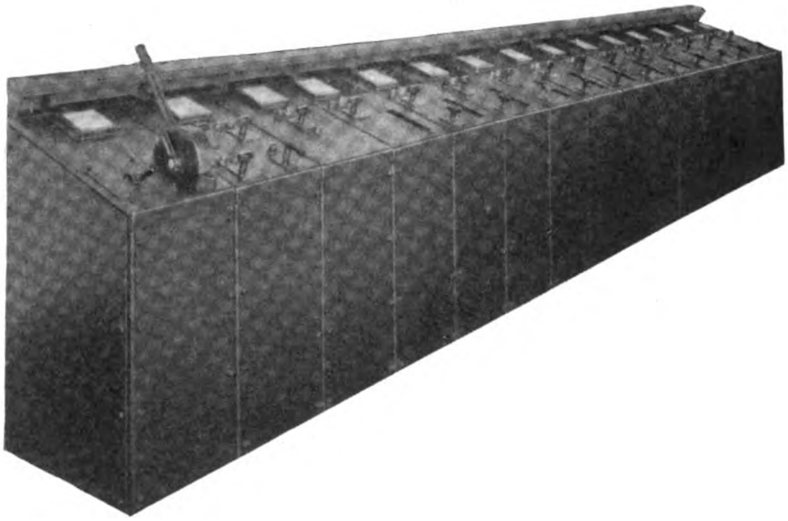


Fig. 107. Steel Bench-type Board for the Control of Steel-mill Motors

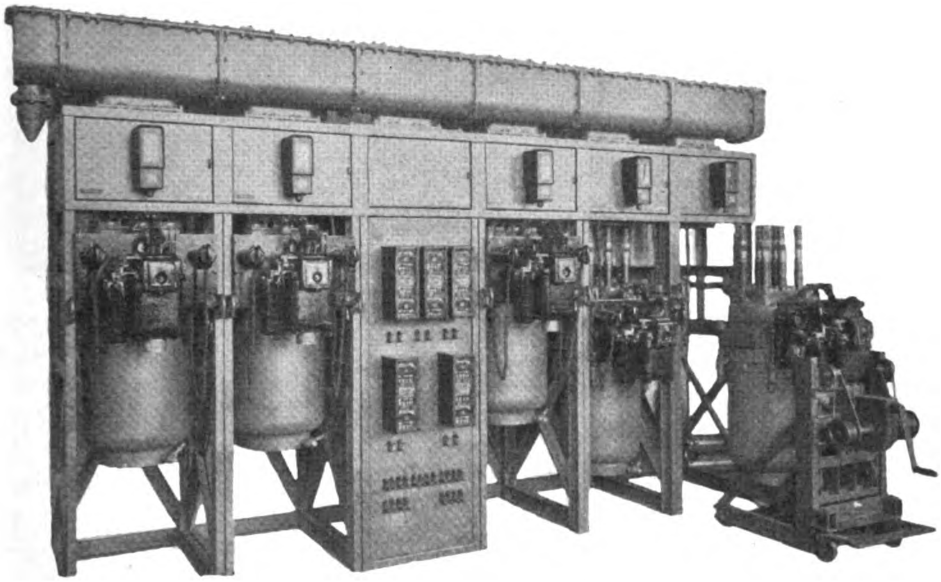


Fig. 108. Indoor Metal-clad Gear in Connected, Testing, and Removed Positions

Oil Circuit Breakers

Studies of system stability have indicated the need for switching apparatus which, in the minimum of time, would remove line troubles leading to short circuits. Extensive investigation with the explosion-chamber type of breaker (Fig. 109), through arrangements with the Philadelphia Electric Company, included short-circuit tests on the 220-kv. system of that company.

These tests demonstrated that the oil circuit breaker under test operated in a considerably shorter time than the conventional oil circuit breaker and indicated that still further reductions in operating time were possible of attainment.

A new indoor breaker was designed for severe service with interrupting capacities from 350,000 to 2,500,000 kv-a. in various tank sizes from 16 to 36-in. diameter. It uses a separate round tank for each phase (Fig. 110) and is rated for 15,000, 25,000, or 37,000 volts, with normal current ratings up to 4,000 amp. This type was developed to supersede two earlier types of breakers and embodies certain improvements such as a top frame of plate-steel design, formed on the dome principle, and strongly welded throughout; a more substantial mechanism; and an improved contact construction.

The tanks are of plate steel having dish-shaped bottoms. The tanks having 16- and 20-in. diameters are pressed in one piece; the larger sizes are rolled and the seams reinforced with a welded overlap plate. The tanks are secured to the top frames by short bolts with claws which catch a steel band welded to the tank.

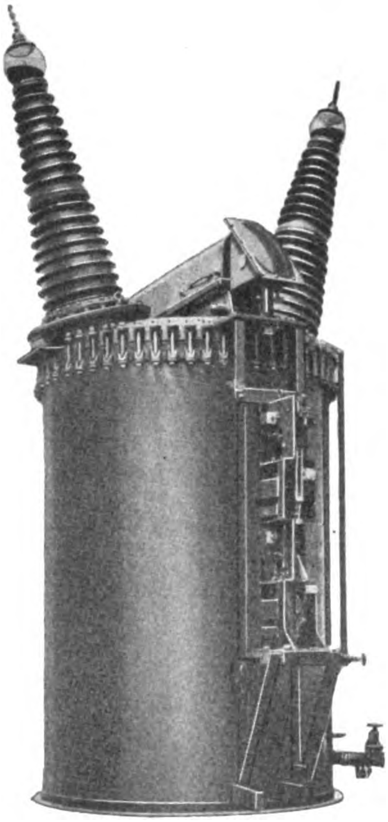


Fig. 109. Single-pole of Explosion-chamber Type of Circuit Breaker Used in Short-Circuit Tests on 220-kv. System

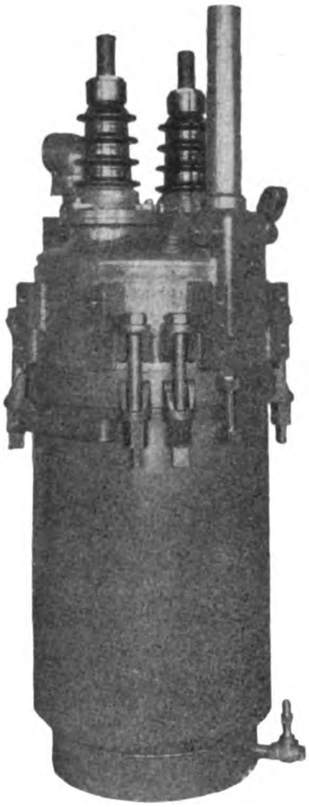


Fig. 110. 25,000-volt 2000-amp. Single-pole Oil Circuit Breaker for Indoor Service

The well-known self-aligning finger and wedge contacts are used for breakers of lower interrupting capacities, while the explosion chamber is used for breaking the arc for the wedge and finger primary contacts on the breakers of higher interrupting capacities.

With the foregoing improvements, together with the retained advantages of the older types, these breakers are suitable for indoor service of maximum severity. They are also available for both indoor and outdoor metal-clad switchgear which is a new field for such breakers.

Another new indoor oil circuit breaker (Fig. 111) serves to disconnect the shunt circuit of an induction regulator when it is inconvenient or impossible to interrupt the exciting current by the feeder oil circuit breaker. It is single-pole, single-throw, non-automatic, and has a rating of 4500 volts, 60 amp. However, it is insulated to withstand repeated high-voltage surges up to 24,000 volts.

It is operated by a switch hook and a safety latch locks the contacts in the closed position. It has a strong frame of formed-sheet steel punchings. The bushings are of one-piece porcelain extending below the oil level. Oil-immersed copper contacts open and close with a wiping motion which tends to keep them clean, and no adjustment is required.

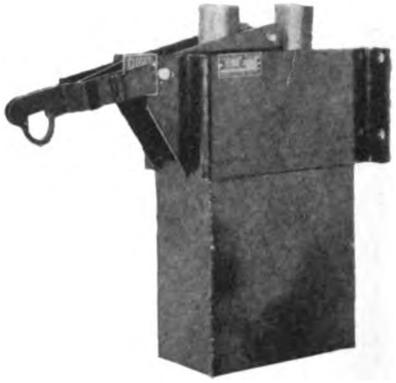


Fig. 111. 4500-volt 60-amp. Single-pole Single-throw Oil Circuit Breaker for Disconnecting Service

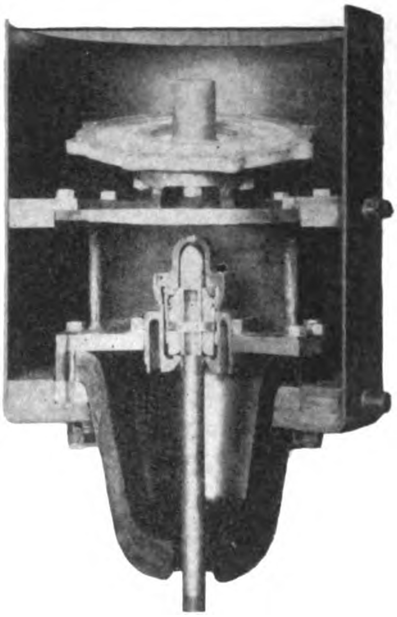


Fig. 112. Non-metallic Explosion Chamber for 220-kv. Oil Circuit Breaker

The explosion chamber has long been recognized as the most efficient means for decreasing the volume of gas generated and the pressure produced in interrupting short-circuit currents at any voltage. The demonstrable decrease in short-circuit time made possible by the use of these explosion chambers has concentrated further attention on their design. This led to the development of a non-metallic explosion chamber (Fig. 112) for use with oil circuit breakers rated from 110 to 220 kv.

The explosion chamber itself is made of Herkolite, moulded at high pressure and cured at a high temperature.

Oil circuit breakers rated 88,000 volts and above can now be equipped with high-voltage capacitance-transformer bushings suitable for operating potential devices to obtain transformation from high voltage to low voltage for the operation of synchroscopes and relays.

The potential device utilizes the charging current of the high-voltage bushing as the source of energy and furnishes a secondary voltage substantially in phase with, and in proportion to, a line-to-ground voltage. Each potential device is contained in a waterproof house which is mounted on the side of the breaker unit adjacent to the high-voltage bushing. Connection is made from the bushing tap to the potential device by means of a lead-covered cable with overlapping and interlocking steel armor.

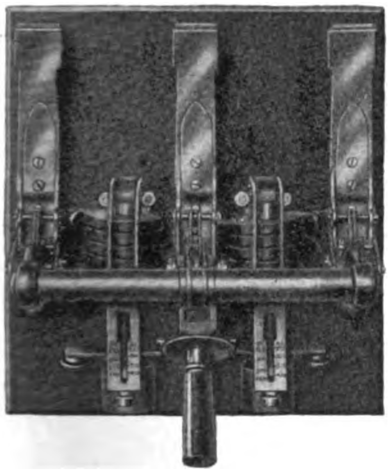


Fig. 113. 650-volt 300-amp. Air Circuit Breaker with Inverse-time-limit Overload Tripping Devices

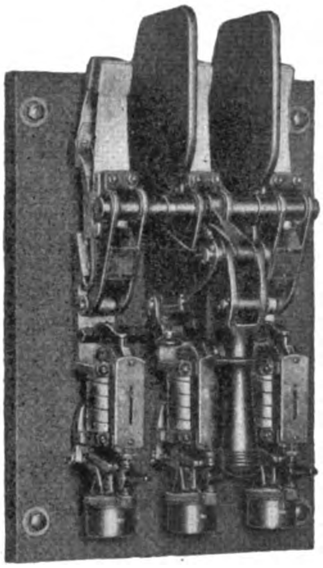


Fig. 114. 650-volt 400-amp. Air Circuit Breaker with Inverse-time-limit Overload Tripping Device on Each Pole

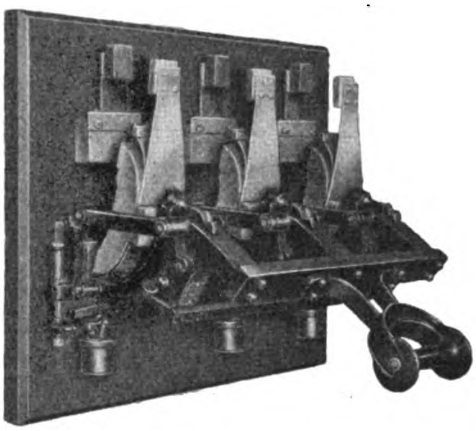


Fig. 115. 650-volt 3000-amp. Air Circuit Breaker with Three Inverse-time-limit Overload Tripping Devices

Air Circuit Breakers

small mechanically-strong air circuit breaker (Fig. 113) was designed for light-duty service and is especially applicable for building equipment. It is made single, double, or triple-pole, in capacities from 3 to 300 amp., 650 volts d-c. or a-c., with automatic overcurrent release, and is trip-free.

A line of substantially-built trip-free air circuit breakers (Fig. 114) was developed for moderate-duty service. They are conservatively rated and have a high interrupting capacity. The width of the breaker is kept at a minimum by locating the over-current tripping mechanism below the breaker poles. This type of breaker is used extensively for general industrial and building equipment service and also on lighting and power switchboards. It is built in capacities from 15 to 1200 amp., 650 volts d-c. or a-c., single, double, and triple pole, complete with accessories.

Another new line (Fig. 115) comprises automatic overcurrent air circuit breakers of the following capacities: single-pole, 1600 to 10,000 amp., 650 volts d.c.; 1600 to 4000 amp., 650 volts a.c.; double-pole 1600 to 6000 amp., 650 volts d.c.; 1600 to 4000 amp., 650 volts d.c. or a.c. They are substantially constructed, have high interrupting capacities, and are designed for the protection of direct-current installations where the current is over 1200 amp. and for alternating-current service that does not warrant the use of oil circuit breakers. They are also suitable for power feeders, building equipment service, or for any other circuit where the load is highly inductive. Being trip-free, they fill a very important need in the application of apparatus of this nature in that the trip-free (so-called non-closable overload rigid arm) type of breaker is rapidly becoming a standard requirement for certain applications, especially in building equipment.

Improvements were made in the design of a single-pole solenoid-operated 650-volt direct-current high-speed switchboard type of air circuit breaker (Fig. 116), which is used extensively in automatic-station and steel-mill service. An inverse-time-limit feature was added, and the line was extended to include 6000 and 10,000-amp. capacities.

Network Protectors

Trip-free motor-operated submersible network protectors were provided with improved features.

These devices (Fig. 117) are for use in low-voltage alternating-current secondary network systems, their function being to disconnect transformers on a primary feeder from the network in case of transformer or primary-feeder short circuits. The motor-operated centrifugal mechanism closes the magnetic blow-out circuit breaker contacts when conditions are normal as determined by the operation of a phasing relay and a polyphase reverse relay. These relays cause the opening of the protector contacts to prevent power flow from the network toward the feeder.

The improved main current carrying contacts are of single-break line type, silver to silver, and are self-aligning. The breaker unit is mounted on insulating bars, instead of the conventional insulating base, providing free circulation of air around the conductors. The breaker unit may be rolled out on rails which are provided in the submersible enclosing case without disturbing or deënergizing the cable connections.

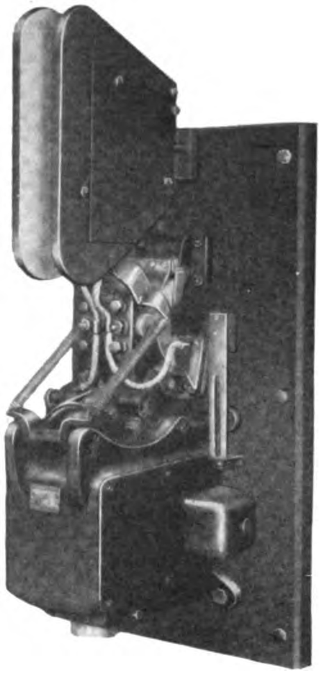


Fig. 116. 650-volt 3000-amp. Single-pole Air Circuit Breaker with Discriminating Overload Trip

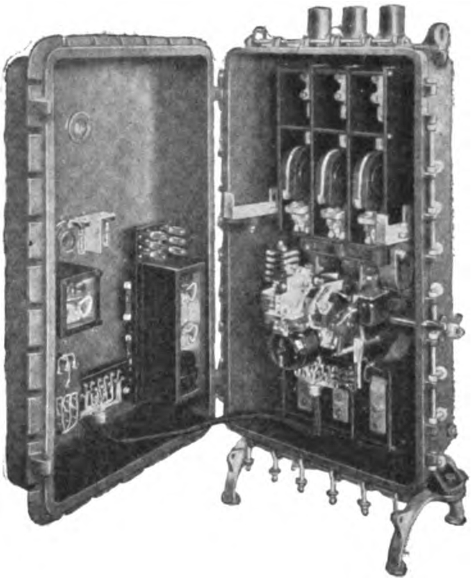


Fig. 117. 250-volt 1200-amp. Submersible-type Network Protector

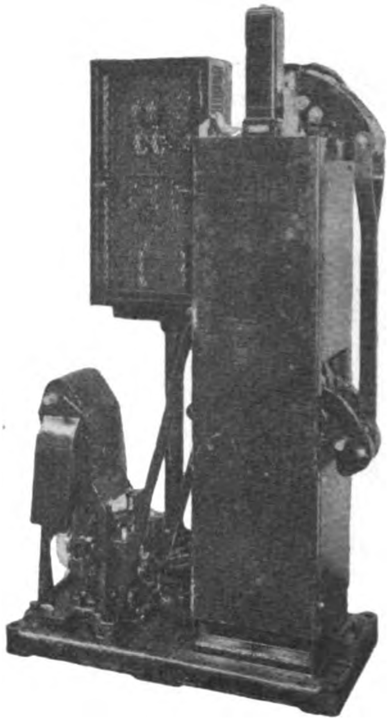


Fig. 118. Motor-operated Mechanism for Use with 5000-amp. Oil Circuit Breaker

Operating Mechanisms

A new centrifugal motor-operated mechanism provides rapid operation of those oil circuit breakers which are equipped with extremely heavy contacts to carry very high normal currents. It employs the well-known centrifugal operating principle used for a number of years in standard motor-operated mechanisms and consists (Fig. 118) essentially of two motors and centrifugal elements which operate in tandem to close the oil circuit breaker.

The improvements include a mechanically-operated control device and a specially designed and reinforced latching mechanism to provide latching and yet not require excessive power to trip.

When used with isolated-phase arrangements of oil circuit breakers, the mechanism for operating the disconnecting switches can be mounted on a supporting base with the motor operating mechanism, and can be interlocked so that the disconnecting switches cannot be opened until the operating mechanism has opened the oil circuit breakers.

A cam mechanism to operate a standard triple-pole double-throw 2500-volt 400-amp. oil circuit breaker for incoming-line transfer service (Fig. 119) consists of a motor, a clutch, a set of four spur gears, cams, and auxiliary switches.

When the motor circuit is energized, the pinion gear on the motor shaft drives a gear wheel which is keyed to the operating shaft on which are fastened two cams. A roller on the operating crank of each throw of the breaker engages this cam and as the motor rotates the cam raises the operating crank, closing one throw of the breaker. The cams are so arranged on the shaft that reversal of the motor allows one throw of the breaker to open while the other throw is closing.

The shock of the closing stroke is absorbed by a disk-clutch between the motor and the pinion gear, and a buffer is provided which acts as a stop for the closing stroke of the mechanism, at which time the motor circuit is opened by means of an auxiliary switch. The motor is rated $\frac{1}{6}$ hp. and can be operated on 220 volts a.c. or 125 volts d.c.

Provision is made for manual operation by means of a crank which can be attached to one side of the mechanism.

A new form of indoor bus clamp and bus-support fitting (Fig. 120) is made of non-magnetic steel with a circular pad or raised portion on the face of the clamp that contacts with the bus bar. The clamps have high mechanical strength and maintain uniform pressure on the bars; and as the pad is circular, line contact between the clamped bars is obtained. The advantage of this new design is that it obviates the tendency of the bars to bow away from each other at the center as the clamps are tightened, a condition which is present in the flat-face form of clamps and which causes lost contact surface.

Relays

A very sensitive ground-fault protective relay is actuated by means of the current in the three phases of a three-phase circuit. It has one operating coil supplied by the residual current from three line current transformers and three restraining coils. Differences in the current transformers cannot cause false operation due to the restraining action. There are two disks mounted on a common shaft (Fig. 121), each disk actuated by two U-magnets. This relay is especially valuable for bus differential protection against very small ground-fault currents.

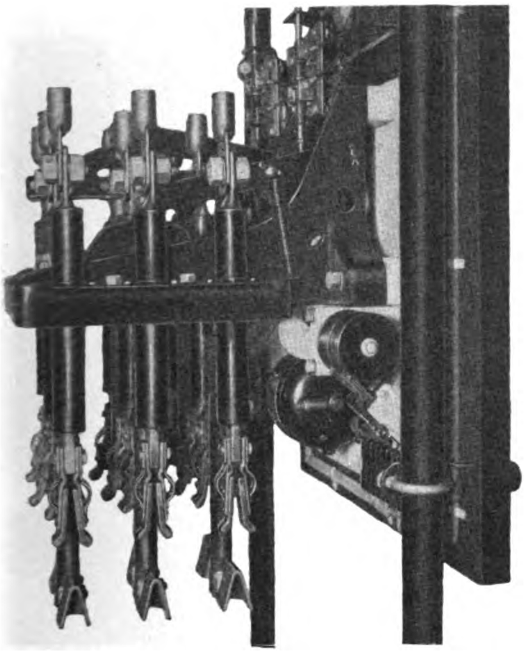


Fig. 119. Cam Mechanism for Operating Standard Triple-pole Double-throw 400-amp. Oil Circuit Breaker

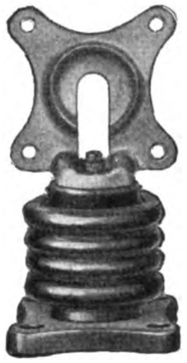


Fig. 120. Indoor Non-magnetic Steel-clamp Bus Support, Showing Circular Pad for Localizing Contact Pressure

A new induction-type overcurrent undervoltage relay having the same application as the standard overcurrent relay has the additional feature of a restraining action due to the voltage across the line. Where the system generating capacity is changed frequently, which would require a change in the setting of the ordinary overcurrent relay, its advantages are most outstanding. Its general application is similar to that of standard overcurrent and power-directional relay schemes and it is especially useful where sufficient time selectivity cannot be obtained by ordinary means. The construction is similar to a standard induction overcurrent relay having an operating coil actuated by the current in the line. It also has a U-magnet with a voltage coil which restrains or opposes the overcurrent or operating element and which is actuated by the voltage across the power transmission lines.

This same overcurrent-undervoltage relay was made available in a high-speed type with a minimum definite-time delay of two cycles on a 60-cycle basis. In construction, the high-speed type has the contacts mounted directly on the disk shaft and no permanent damping magnet is used.

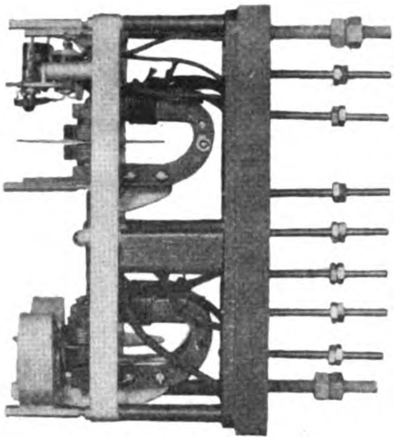


Fig. 121. Differential-current Relay for Ground-fault Protection

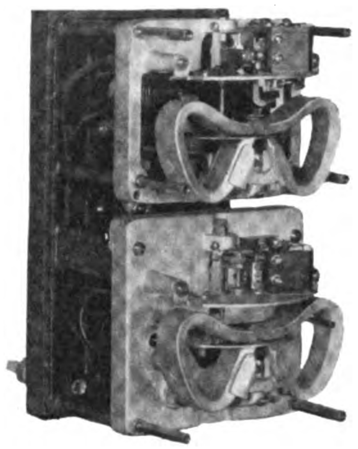


Fig. 122. Power-directional Overcurrent Undervoltage Relay

A companion type of the overcurrent-undervoltage relay (Fig. 122) has a power-directional element in addition to the overcurrent-undervoltage element. The contacts of these two elements are connected in series so that the trip circuit is completed only when the power flow is in the proper direction.

For use with high-speed oil circuit breakers, a balanced-current relay was developed which operates on 1½ cycles, based on 60-cycles, at currents slightly in excess of its minimum operating value and at lower periods on higher currents. It is used for parallel-line protection and is restrained by the voltage between the lines. It has two elements, each consisting of a rotating armature acted upon by an operating winding and two restraining windings, one current and the other voltage. The use of the restraining-voltage winding permits the relay to be set below full load on one line without having the relay in the operating position during single-line operation. The two elements have their current coils cross-connected and give balanced protection between similar phases of two parallel lines. Three lines are used for phase-to-phase protection and an additional one for ground protection, connected in the residual circuit of three current transformers.

An induction-type network phasing relay (Fig. 123), independent of phase rotation, will close its contacts when the transformer voltage leads the network voltage. The potential coil of this relay is energized by the phase-to-neutral voltage and the phasing coil by the drop across the open protector on the same phase. When used with the polyphase network relay, the combination will prevent the closing of the protector when a condition exists which will cause "pumping," *i.e.*, alternate opening and closing of the protector.

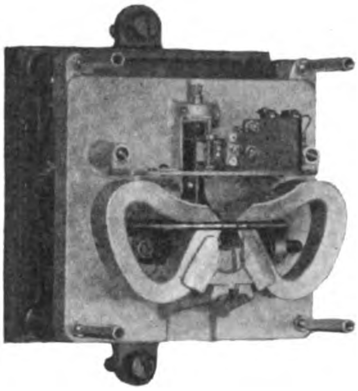


Fig. 123. Induction-type Network Phasing Relay

A time-delay voltage relay of the induction type was also developed which guards against an open phase or incorrect phase rotation in a three-phase system and requires a certain predetermined value of voltage to operate. A lever for adjusting the time delay is provided which will give five seconds delay with normal voltage.

INSTRUMENTS AND METERS

A new oscillograph for general purpose use was made available (Fig. 124 and 125). This is a six-element instrument of the permanent-magnet galvanometer type with all essential parts arranged compactly for simplicity of operation. The galvanometers are of unique design. Single and polyphase wattmeter elements are interchangeable in the case with the usual voltage and current galvanometers. The light source is an incandescent lamp. Film holders of the magazine type for three or five exposures, and of the continuous-drive type for long films are available. The operation of the oscillograph is from a single power source, either a six-volt storage battery or an a-c. supply.

Four single-phase 60-cycle metering equipments for 220,000-volt circuits were constructed with shielded potential elements (Fig. 126) and coördinated insulation throughout. These outfits will withstand higher impulse voltage than the line insulation.

The potential element is built on a two-legged core and the coils are stacked on one leg surrounded by a shield, thereby rendering the transformer non-resonating under transient conditions.

The current element is also built on a two-legged core with one low-voltage coil on each upright leg, and the high-voltage winding over one of the low-voltage coils. The four high-voltage coils may be connected in series, series multiple, or multiple at the top of the high-voltage bushing for ratings ranging from 150 to 600 amp.

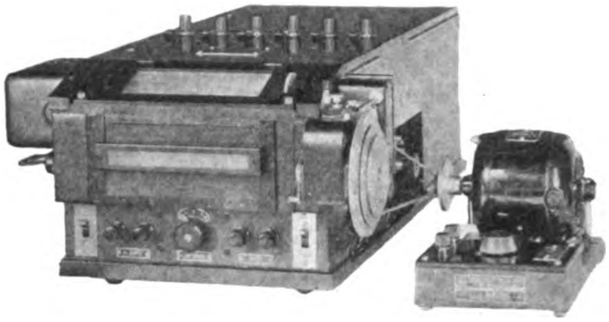


Fig. 124. Six-element Permanent-magnet Oscillograph with Driving Motor

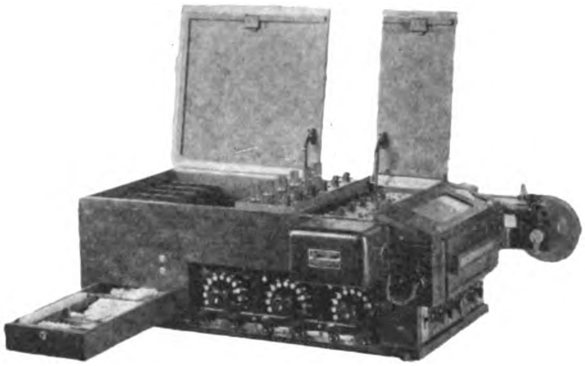


Fig. 125. Six-element Permanent-magnet Oscillograph Open for Inspection

The bushing designed for this equipment is 18 ft. long and weighs 4000 lb., and the complete outfit requires 46,500 gal. of oil; the total weight with oil being 76,500 lb. These are the highest voltage metering equipments so far constructed.

In the measurement of temperature by means of thermocouples, it is necessary to have the equivalent of a fixed temperature of reference. In a new instrument this equivalent is supplied by the use of a temperature-sensitive magnetic counter-torque in addition to the ordinary spring control. This instrument will be particularly useful in numerous applications of temperature measurement where the measuring apparatus, as distinguished from the thermocouple itself, is likely to be subjected to a wide range of temperatures. Calmaloy, the magnetically temperature-sensitive material used for temperature correction in watthour meters, is the material used and is the key to this form of temperature measurement.

A new magnetic circuit for current transformers was perfected, in which a few secondary turns appropriately placed include only a portion of the core so that the effect of the changes of permeability with change of current in closely related portions of the core is such that a considerable reduction of the ratio errors of the transformer is secured. Also by means of short-circuited bands, short-circuited with relation to only a portion of the core flux, a reduction in the phase-displacement error is obtained. The action of both of these means of correction is such that at low currents, where the need for correction is greatest, the largest effect is produced.

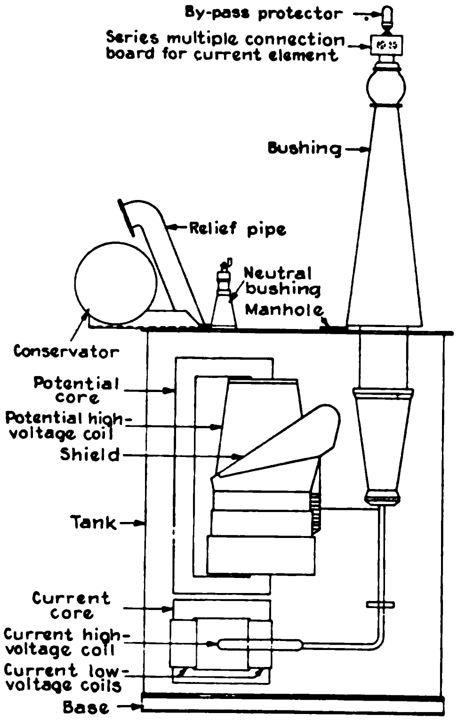

By-pass protector
Series multiple connection board for current element
Bushing
Relief pipe
Neutral bushing
Manhole
Conservator
Potential core
Potential high-voltage coil
Shield
Tank
Current core
Current high-voltage coil
Current low-voltage coils
Base

Fig. 126. Diagram Showing Construction Features of One Unit of 220,000-volt Metering Equipment

A new form of telemeter receiver is intended for use with other telemetering apparatus of the class in which the quantity to be indicated is represented in the communication circuit by a series of impulses of a frequency proportional to that quantity. The new receiver makes use of the current that appears in a secondary circuit as the consequence of the magnetic discharge of an iron core. The core and circuits associated with it are so designed and proportioned that the quantity of electricity discharged, and consequently the instrument indications, are independent of the voltage of the exciting circuit. The receiver may be made either as an indicating or as a recording instrument and is well suited to the measurement of power and indeed of any quantity that can be represented as a series of impulses of a frequency of the order of two or three per second for the full scale of the instrument.

A complete new line of rectangular instruments (Fig. 127), uniform in size and appearance, was designed for both alternating-current and direct-current service. The line includes ammeters, voltmeters, wattmeters, reactive-volt-ampere meters, power-factor meters, and frequency meters. The instruments are uniformly 6 in. high by 5½ in. wide by 3½ in. deep, thereby making it possible to mount four instruments across the face of a 24-in. switchboard panel.

A special non-glare glass is used which, in combination with an anti-parallax scale and pointer, facilitates reading regardless of the angle from which the instruments are viewed.

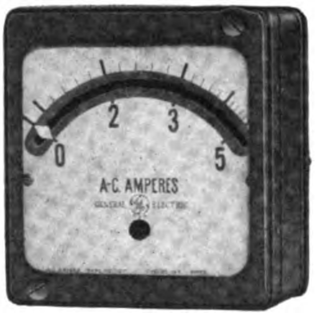


Fig. 127. Typical Unit of Standard Line of Rectangular Instruments

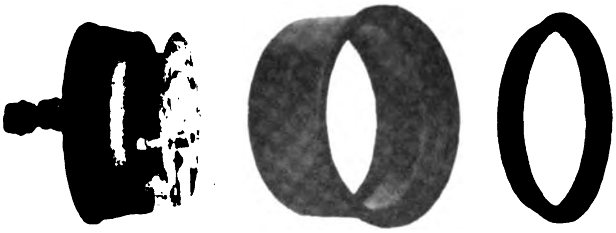


Fig. 128. Miniature Ammeter with Cover Removed, Showing Threads and Removable Glass

Internal resistances are used with all instruments with potential circuits except for the higher-voltage polyphase wattmeters. The moving elements are provided with ground steel pivots mounted in sapphire bearings. "Dead-beat" indications are obtained by means of magnetic damping.

Miniature instruments of improved construction were designed for 2¼ and 3-inch dia. cases for use on both alternating-current and direct-current lines.

They are provided with moulded compound case and bases (Fig. 128), the case being threaded so as to screw on the base. The line includes instruments for use on low-voltage alternating-current circuits. These instruments are of high resistance (1000 to 2000 ohms per volt). This high resistance in an instrument for low-voltage alternating current is made possible by the use of rectifiers which are provided inside the case of a direct-current instrument.

LIGHTING

A preliminary estimate of the number of incandescent lamps sold in the United States during 1929 (Fig. 129) indicates 340 million large and 292 million miniature lamps. The former is an increase of 18 million or a little over 5½ per cent, and the latter an increase of 37 million or 14½ per cent over 1928. These 1929 sales exceed all previous figures, being the largest in the history of the industry.

On March 1, 50 and 60-watt standard lighting lamps of the 115-volt group were reduced in list price from 22 to 20 cents so that the 20-cent price now covers all the generally used lamps up to and including the 60-watt size. The price trend for lamps (Fig. 130) has been downward for a number of years; the present prices being less than half the so-called pre-war figure.

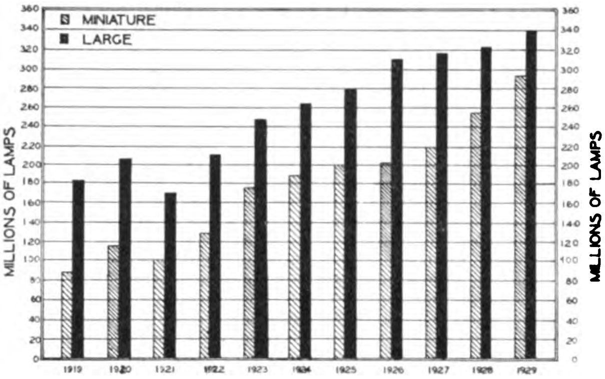


Fig. 129. Number of Incandescent Lamps Sold in the United States 1919-1929. (1929 estimated)

Compare this with the present cost of living which is now 60 per cent above the pre-war level, a peak of 100 per cent increase having been in effect during 1920. While the average prices of lamps did go up during the post-war period, their increase was less than one-tenth that of the increased cost of living during the same period.

The sun lamp which differs in many respects from other ultra-violet-producing light sources was developed. It produces results like sunlight, in equipment which is simple, inexpensive to operate, and requires a minimum of attention. The source of the ultra-violet radiation is a new form of lamp (Fig. 131) which is similar to the standard incandescent lamp in that the light source is contained in a bulb that screws into a socket in the usual manner.

The light and radiation-giving parts of the lamp consist of an arc in mercury vapor between tungsten electrodes, and an incandescent filament; the electrodes and incandescent filament supply the light while the arc adds the desired ultra-violet radiation and some light. A special glass bulb is used, which permits the emanation of only that part of the ultra-violet radiation that is effective and safe. The light from this lamp contains the full spectrum; is pleasing in quality, being whiter in appearance than ordinary tungsten light; and combines in a simple and convenient way illumination and ultra-violet radiation.

As the lamp requires a low-voltage source, it must be operated with a transformer and it is essential that the transformer be designed for operation with this lamp, since the operating characteristics of the lamp are determined by the transformer. When the switch is closed, the lamp requires approximately 30 volts and 9 amp. As soon as the arc strikes, which normally takes a fraction of a second, the lamp voltage drops to approximately 11 volts with a total current requirement of 30 amp.

The new equipment designed for this lamp (Fig. 132) contains the transformer in the base, and is intended for operation only on 60-cycle alternating-current circuits of standard voltages, *i.e.*, from 110 to 125 volts.

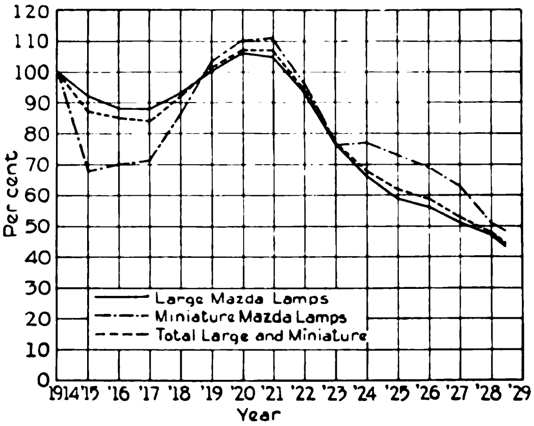


Fig. 130. Range of Lamp Prices on Principal Types of Domestic Mazda Lamps, 1914-1929

The ordinary applications of incandescent lamps seldom bring to our attention or consideration the quantity of heat which is produced as a necessary consequence of the light emitted by incandescent tungsten. However, in certain special applications of high-intensity illumination, the heat generated is not only brought to our attention, but is impressed on our minds through physical discomfort. Some of these special applications are in studio lighting for colored and talking motion pictures, projection of motion-picture films, opaque projection, and the lighting of the operating tables in hospitals.

In round numbers, 85 per cent of the energy radiated by a 1500-watt tungsten lamp is in the infra-red region and constitutes the heat which we desire to eliminate. This is achieved by absorbing the heat in some liquid, which absorbs much of the heat but transmits most of the light. Water or some solution such as copper chloride may be used as the absorbing medium and the heat may be dissipated by means of a cooling coil.

The unit at present in the process of development (Fig. 133) consists of a lamp immersed directly in the absorbing liquid which is confined by an outer glass jacket. A cooling coil through which tap water is circulated is also immersed in the absorbing liquid. Convection currents set up within the liquid are sufficient to maintain a circulation, and no mechanical stirring is necessary. The lamp, cooling coil, and outer jacket are all supported from a base plate on which the lamp socket is mounted. Two gaskets, one between the base plate and the jacket, and the other between the base plate and the lamp at a point just below the base, make the unit water tight.

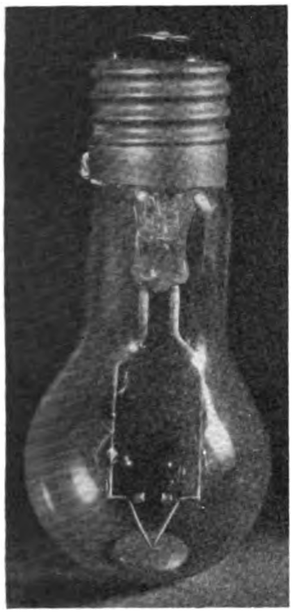


Fig. 131. The Sun Lamp Showing the Arrangement of Filament, Electrodes, and Mercury Pool

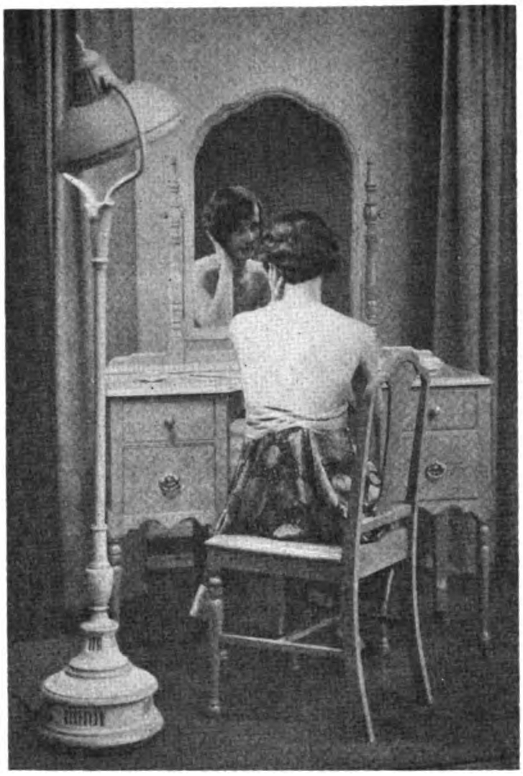


Fig. 132. The Sun Lamp, Showing Standard Containing Transformer and Method of Using the Lamp

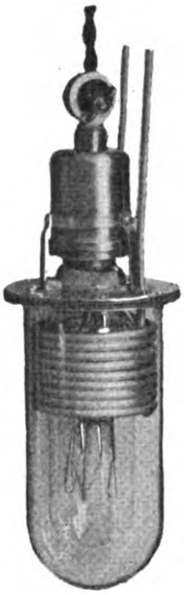


Fig. 133. Water-cooled Lamp, Showing Outer Globe and Location of the Cooling Coil

This arrangement has several advantages. The absorbing layer of liquid practically surrounds the light source so that almost no radiation reaches the atmosphere of the room except through the absorbing medium. Cooling water is circulated in and confined by the coil so that either distilled water or some heat-absorbing solution may be kept permanently in the jacket. The jacket and lamp surfaces are thus kept clean and free from the deposits of ordinary tap water, although tap water is the cooling agent. Another advantage is the possible use of smaller bulb sizes; the temperature of the bulb not being a limiting factor in this case.

In one series of tests, a 1500-watt 115-volt filament was mounted in a special 2½-in. tubular bulb and ordinary tap water (16 deg. C.) flowing at the rate of 20 gal. per hr. through the cooling coil maintained the temperature of the absorbing cell at 45 deg. C. Eleven hundred and twenty-five watts (75 per cent) were dissipated in the cooling water while the absorption of light due to the water cell was only five to seven per cent.

Bulb blackening has always been a significant factor in determining the useful life of incandescent lamps, and is of especial importance in the case of the large-filament high-intensity gas-filled type of lamp. The rising gas in such a lamp carries along evaporated tungsten, which is deposited on the cooler top and sides of the bulb. This tungsten "soot" absorbs considerable energy and in time the glass of certain high-voltage lamps undergoes devitrification, eventually becoming so hot that the bulb becomes distorted and useless.

A new deposit-remover which has been developed to overcome this trouble (Fig. 134) consists of a tablespoonful of coarse tungsten powder, placed inside the lamp before it is sealed. After the lamp has become blackened from use, the operator may remove the lamp from its socket, invert it, and "sweep" the filament deposit off the inner glass surface; the lamp being thereby restored to its former efficiency. With the bulb-blackening difficulty practically removed, the lamp filament may be heated much nearer to its melting point, without endangering the bulb and without shortening the customary life for which the lamps are designed.

This new method has been applied to several high-intensity lamps, including the 1500-watt, 32-volt, the 3000-watt, 32-volt, the 5000-watt, 115-volt, and the 10,000-watt, 110-volt lamps for aviation service; and the 5000 and 10,000-watt, 115-volt lamps for motion-picture studios.

The International Commission on Illumination organized new technical committees to specialize on Applied Lighting Practice, Aviation Lighting, and Lighting Education, the secretariats for the two former topics being assigned to the United States.

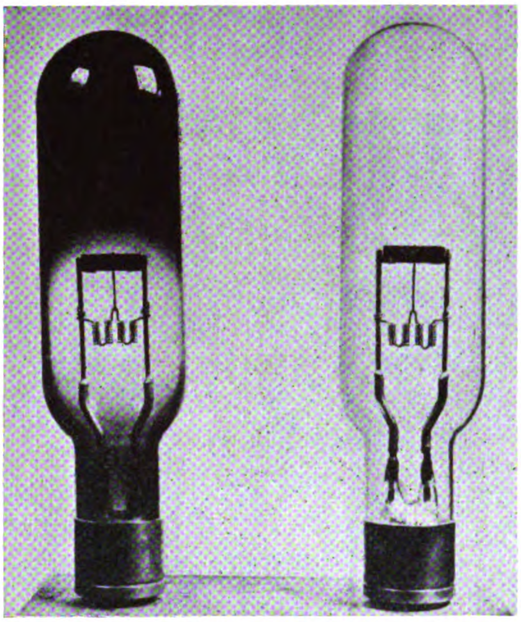


Fig. 134. High-power Incandescent Lamp Containing Cleaning Powder. Left: before removal of deposit. Right: after sweeping deposit from the bulb

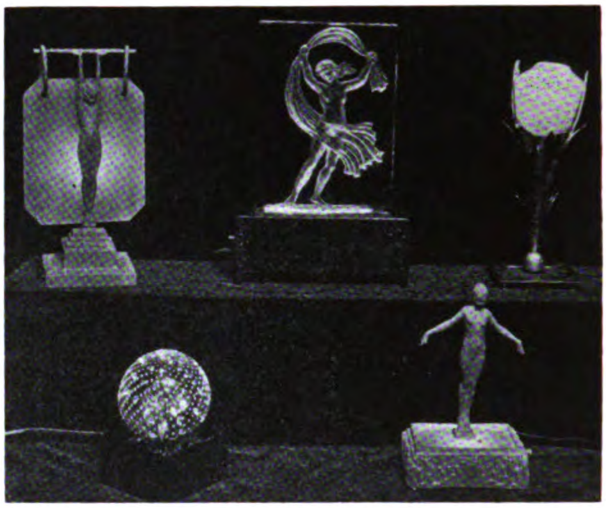


Fig. 135. Recent Types of Light Ornaments of American Design

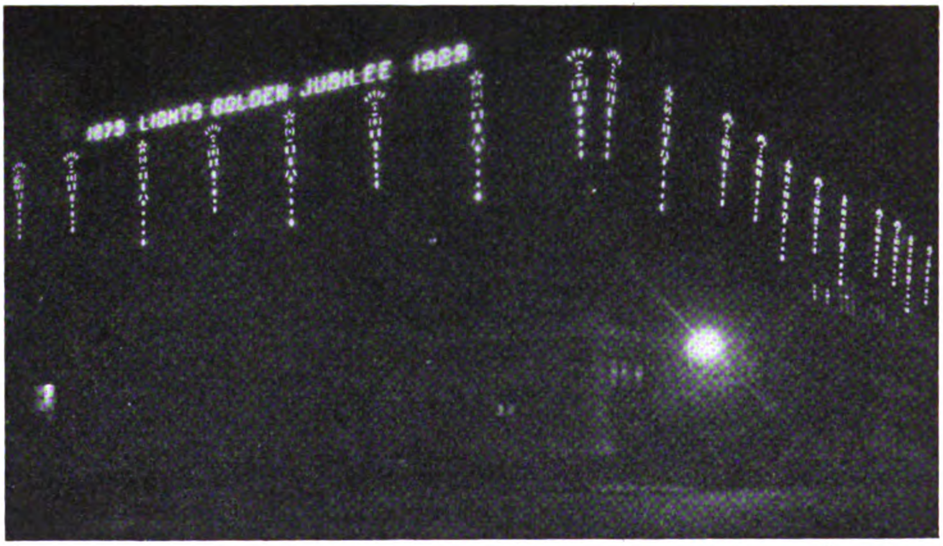


Fig. 136. Light Applique, a New Development in Decorative Lighting

At the suggestion of the U. S. National Committee, the administration recommended the "Light's Golden Jubilee" celebration to the attention of the various national committees, and most of them coöperated actively. Among the countries evincing special interest were Argentina, Austria, Brazil, Chile, China, France, Holland, Italy, Japan, Mexico, Portugal, and Sweden.

Japan was particularly active in the development of better lighting practice and a mission of eighteen executives and engineers, representatives of the Japanese electric lighting utilities, visited this country to study lighting methods and attend "Light's Golden Jubilee" celebration at Dearborn (Mich.).

Probably the outstanding educational undertaking of the lighting industry was that of National Electric Light Association to encourage lighting service engineers in seeking the coöperation of architects, to the end that more adequate wiring might be provided to meet illumination needs in new commercial and industrial buildings. Lack of such wiring is a serious impediment to good lighting practice. Model Specification Paragraphs have been prepared to express the quantity elements required in simple definite terms.

As has been the practice for several years, the Mazda lamp manufacturers continued to hold schools of approximately a week's duration to educate central-station lighting men, distributors' representatives, and others in the fundamentals of lighting practice, as well as in the detailed treatment of special fields. In 1929, fifteen such schools for intensive training were held with a total attendance of approximately 700 individuals.

The tendency to superimpose spots of high light in color (Fig. 135) on the general illumination of the home continued to grow and many new types of these light ornaments were produced.

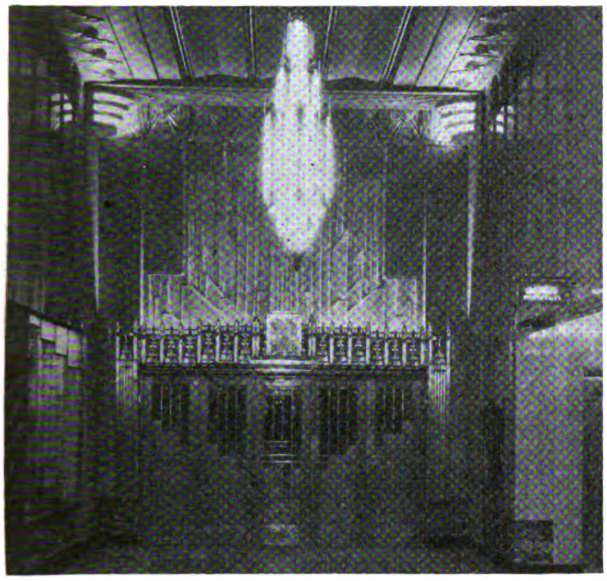


Fig. 137. Lighting Units Designed to Harmonize with the Structural Decorative Scheme of a Building

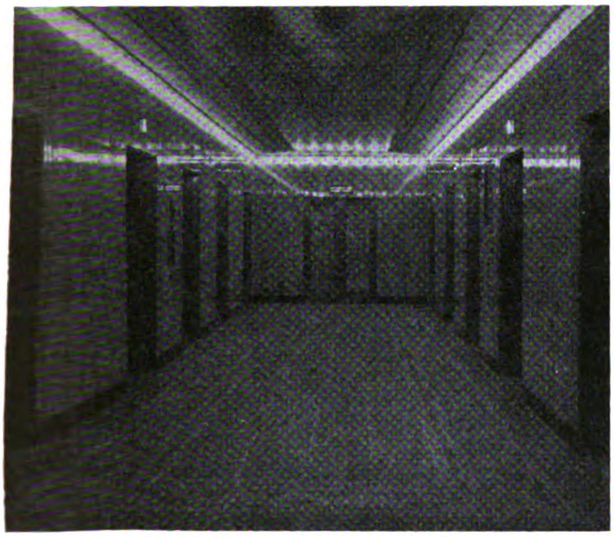


Fig. 138. Luminous Panel Lighting for Hallway

The most important means of decoration in connection with "Light's Golden Jubilee" celebration was light itself and many novel effects were thereby obtained. Among the various methods used were floodlighting, outline lighting, luminous jewelry, light appliques (Fig. 136), mobile color fountains, jeweled arches, arc-light scintillators, floodlighted waves, golden street lamps, and canopies of golden light on business streets.

The modernistic movement in light and decoration increased remarkably and practically no new public building of importance was erected during the year without the incorporation of some of the new treatment in its structure. Whereas a few years back the artificial lighting arrangement was largely an afterthought, it is now being logically incorporated into the design of the building itself (Fig. 137), resulting in illumination through luminous wall panels (Fig. 138), through diffusing boxes, built around ceiling beams, and from fixtures which are in harmony with the structural contour and decorations.

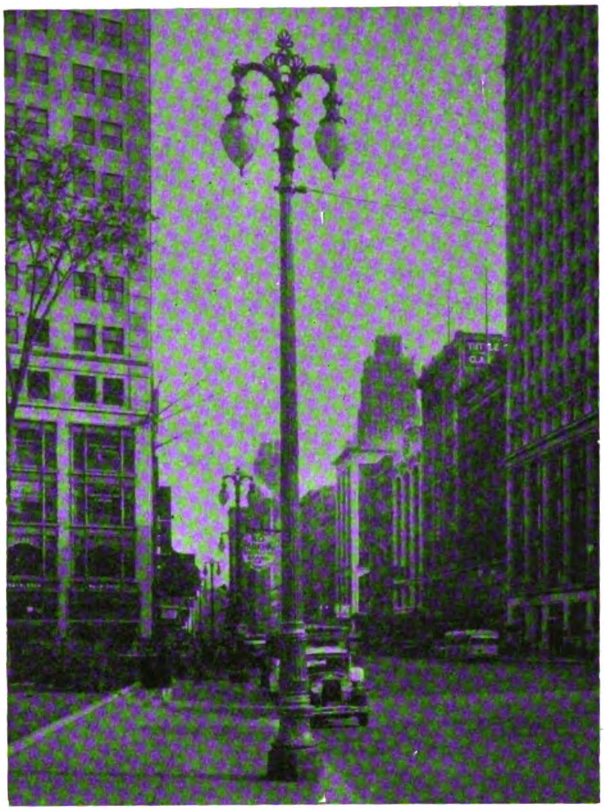


Fig. 139. Woodward Avenue, Detroit (Mich.), Showing Type of Lighting Standard Adopted to Produce Highest Intensity of Street Illumination so Far Applied

The architect and lighting equipment artist have now combined their efforts and, although this so-called *art moderne* movement originated abroad, American architects have recently contributed much to its development.

Street Lighting

Detroit became the possessor of the best-lighted business district in the world when the new lighting system for downtown Woodward Avenue and adjacent streets was turned on in March. The lighting equipment consists of two parallel rows of standards, 100 ft. apart on opposite sides of the street. On each are mounted two ornamental lighting units, utilizing rippled glass to give a maximum diffusion of light with a minimum of glare, and equipped with 2000-watt Mazda lamps. They are the largest suspension-type street-lighting units so far constructed (Fig. 139) and give an illumination intensity of approximately 1900 lumens per linear foot of street.

A new design Eternalite unit (Fig. 140) consists of a simple porcelain which acts as a housing for the socket, an insulator, and a reflector. This unit may be used for either internal or external wiring as a reflector without enclosing glassware, or for internal or external wiring with hinge and latch to take enclosing glassware. Formerly, four separate porcelain pieces were required in order to perform these functions.

A new combination street and floodlighting unit was designed. This may be used for illuminating building fronts or for lighting the grounds of gas-filling stations, etc., in addition to its street-lighting function.

The interior part of each unit has a copper-backed silvered-glass reflector attached to a support (Fig. 141) which is adjustable in a vertical angle so that the floodlighting beam may be directed either upward or downward. The support is held by a cross-piece fastened to the casing. In all types of this unit, a medium screw-base socket for an auxiliary lamp is supported in such a position that the lamp will illuminate the white coated back of the reflector and avoid objectionable shading of the outer globe.

Motor-vehicle Lighting

The most outstanding development in motor-vehicle lighting was the adoption of the fixed-focus type of headlight by two of the high production cars—Chevrolet and Overland-Whippet.

For a number of years, most cars have been equipped with headlights which, when properly adjusted will give fair road illumination with very little glare to approaching drivers. Until the adoption of the fixed-focus type of headlamp, practically all cars were equipped with headlight units having one, and in some cases, two, adjustments for focusing the filament in the reflector to get the desired concentrated beam pattern and one other adjustment to aim the beam at the required height to get good road illumination without producing serious glare to approaching drivers.

The difficulty in getting the car owner to keep the headlights in proper adjustment has, to a large extent, been responsible for the highly unsatisfactory night-driving conditions. Several of the states have endeavored to correct these conditions by requiring car owners to have their headlights, as well as other equipment, inspected and adjusted if necessary, at regular intervals. While the activities of the several states have helped, they have by no means entirely corrected the unsatisfactory conditions.

The adoption of the fixed-focused type of headlight which eliminates focusing adjustment should, therefore, have a far-reaching effect when it is adopted by other car manufacturers and existing cars with the old type of equipment are replaced by new cars.

High-quality accurately-made automobile headlight lamps have, to a great extent, made possible the design of the fixed-focused type of headlight. Mazda lamps as manufactured today have filaments so accurately aligned with the base that, with the proper design of reflector and lens, it is possible to eliminate the focusing adjustment.

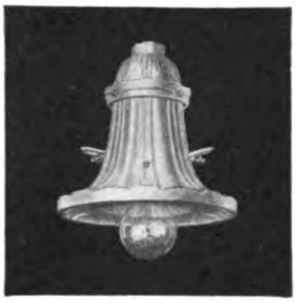


Fig. 140. Simple Structure of Eternalite Porcelain Lighting Fixture Without Enclosing Globe

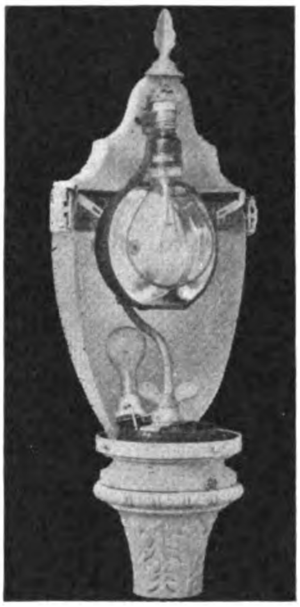


Fig. 141. Arrangement of Lamps and Reflector in Combination Street and Floodlighting Unit

Mechanical features of headlight units have also been improved. The reflectors and housings have been made more substantial so that there is less tendency for the reflectors to warp, with consequent distortion of the beam. Methods for fastening the units to the chassis have been developed which allow easy adjustment of the unit for aiming and yet when once fastened in place hold the headlight lamp in proper position.

During the year, there was an increase of about 100 per cent in the sale of 32-cp. headlight lamps. This is significant in showing the trend toward higher candlepower headlight lamps. Sixteen states still have laws or regulations limiting the candlepower of automobile headlight lamps to 21 cp. These laws were intended to reduce glare by limiting the amount of light and were made at a time when, with the existing equipment, it was not possible properly to control the light beams.

More and more people have come to realize that to drive at the customary speeds prevailing today, more light is required on the road than can be obtained from 21-cp. lamps. Statistics of night accidents show that sufficient light on the road is just as important, if not more so, than an absence of glare. With the present headlighting equipment kept in proper adjustment, there is no reason why 32-cp. lamps should not give greatly improved road lighting without objectionable glare.

Traffic Control

In an effort to promote standardization, the American Engineering Council sub-committee on street-traffic signs, signals, and markings published a report which became the basis for a national standardizing effort. Three states have already adopted state codes based on the findings of this report, all tending toward the gradual unification and standardization of controls and apparatus throughout the United States.

For purposes of manufacture, control systems have been grouped into logical combinations based on geographical application and location, and standardized to meet all control requirements, from those of an isolated intersection located in an outlying district to the control of traffic in a congested business area.

For convenience in the selection of the proper control for application to a given area, the apparatus has been segregated into three main groups as follows:

(1). Control for main business districts. (*Impulse control*).
(2). Control for secondary business and residential areas. (*Synchronous control*).
(3). Control for outlying districts and isolated intersections.
  (*a*). Completely automatic control. (*Induction motor*.)
  (*b*) Traffic-operated control. (*Sound and button operated*).

For the downtown business area, the impulse-control system provides for the flexible progressive flow of traffic and the speed of such flow may be varied from a central point to meet the different traffic densities and weather conditions. It allows the movement of vehicles on the main street to be continuous throughout, but at speeds depending on local conditions. Interconnecting cable is required between intersections, with impulse receiver timer boxes at each intersection. A transmitter timer box is necessary at the central control point and special central control panels may be used to give additional flexibility.

The synchronous-motor control system provides for the progressive flow of traffic at a fixed predetermined rate of speed. This is for secondary business districts, residential areas, and highways where the instantaneous change of the total time cycle throughout the area from a central point is not required.

For isolated intersections in outlying districts on heavily traveled highways where the side street traffic is only periodically heavy, there is a distinct need for a control that will interrupt the main-street traffic only when there is traffic on the side street waiting to cross. Control apparatus was designed to effect this type of operation and the traffic itself, passing through the intersection, operates the control for a standard signal.

The induction controller is used for the main controlling mechanism of the older type of downtown network system and for operating isolated intersections where no traffic operated controller is desired, or where an easily adjustable total time-cycle range is required, and where the signals at that intersection are not required to keep in step with adjacent intersections.

Radio interference with regard to traffic signals was studied and considerable improvement was secured by lighting engineers in collaboration with radio engineers in correcting radio troubles. Standard radio filters consisting of combination condensers and choke coils of various sizes were recommended and are installed in traffic-control circuits, where radio interference is reported, as close as possible to the contact-making element which causes the interference.

During the year, several modifications of existing apparatus were made to improve economy and flexibility. A combined manual and automatic receiver box similar to the type installed in the city of Pittsburgh is larger in all dimensions than the one previously used and provides increased space for the control apparatus.

The mounting or dismounting of the local timer units has been facilitated by the provision of special jack studs on the nine or more circuits entering and leaving the local timer. By this means, it simply is necessary to lift the timer from the suspension hook on which it is mounted in the control box and swing the timer forward, thereby at the same instant disengaging the entire set of contact jacks from their jack receptacles. Thus by a single forward swing of the timer it is possible to remove it from the control box, and as quickly replace it with a spare timer if necessary.

More than 2500 G-E synchronous timers are now in service, the majority of them being of the fixed total cycle type, *i.e.*, there is but one set of driving gears per timer and the timer is arranged to operate at a given total time cycle.

When synchronous timers are installed on an avenue, the total time cycle of the synchronous timers determines the speed of traffic flow through the area. Increase of the time cycle means a corresponding decrease in vehicular traffic flow and vice versa. With the standard fixed total cycle of the synchronous timer, it was therefore impossible to change the speed of traffic flow.

In order to overcome this limitation, a gear-shift synchronous timer was developed (Fig. 142) to provide total time cycles of 40, 50, 60, 70, and 80 sec. By using a screw driver, the proper pair of gears can be slid into mesh to obtain the total time cycle desired. One advantage of this timer is that it will no longer be necessary for a detailed layout to be made of an area before the synchronous-control type of apparatus is adopted.

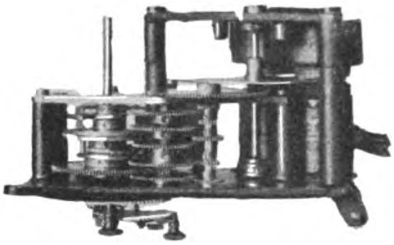


Fig. 142. Synchronous Traffic Timer with Back-adjustable Gearshift

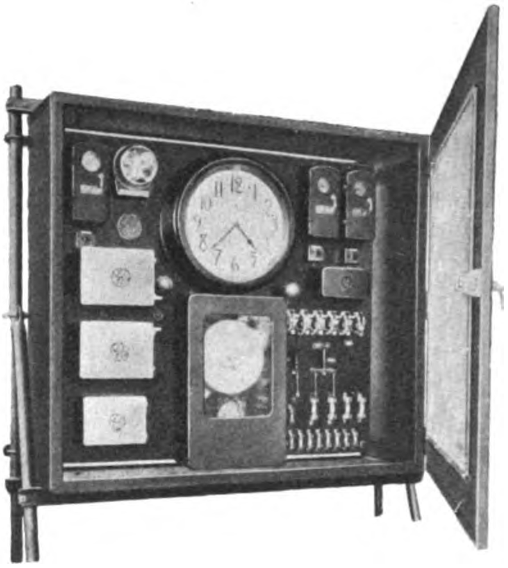


Fig. 143. Central Traffic-control Panel for the City of Pittsburgh (Pa.)

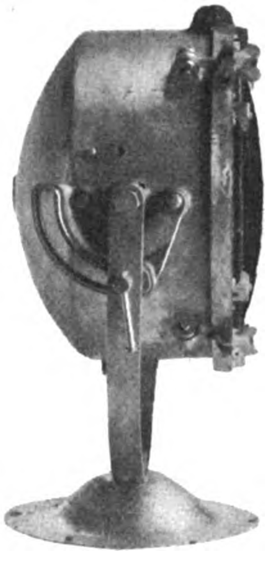


Fig. 144. On-course Airport Light, Provided with Either Red or Yellow Spread-light Lens

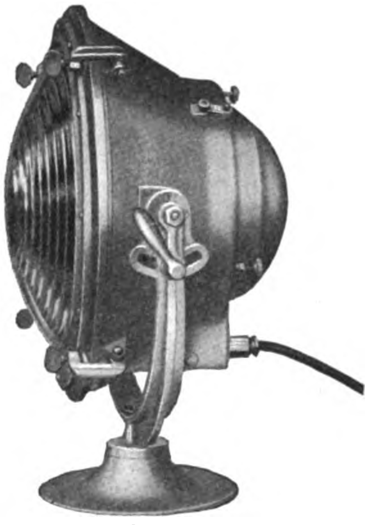


Fig. 145. 18-in. On-course Projector Equipped with Doublet Fresnel Lens

Fig. 146. Airport Boundary Light with Ruby Globe

To provide control for special intersections, bell ringing amber, special left turns, pedestrian-vehicular control, etc., a drum-type receiver timer of exceptional flexibility was developed to care for special requirements such as those calling for pedestrian and vehicular control with all-red period, bell ringing both before and after, etc. It can also be used as a three-street controller.

The most important installation during the year was in the city of Pittsburgh where 86 intersections were provided with an impulse-control system, giving a flexible progressive downtown control.

The master panelboard for this system (Fig. 143) comprises a main transmitter, a substitute transmitter, a means for operating the spare transmitter, an automatic means for throwing over two spare transmitters, and a positive indicating means to visibly assure those in charge that the system is operating properly.

Aviation Lighting

While the Department of Commerce of the United States continued to install lighting equipment on its airways during the year, other countries were following its lead and inaugurating day and night air-mail service. Canada was especially active, and its Department of National Defense, which is responsible for all its aviation activities, let contracts for the installation of a number of beacons at airports and along airways.

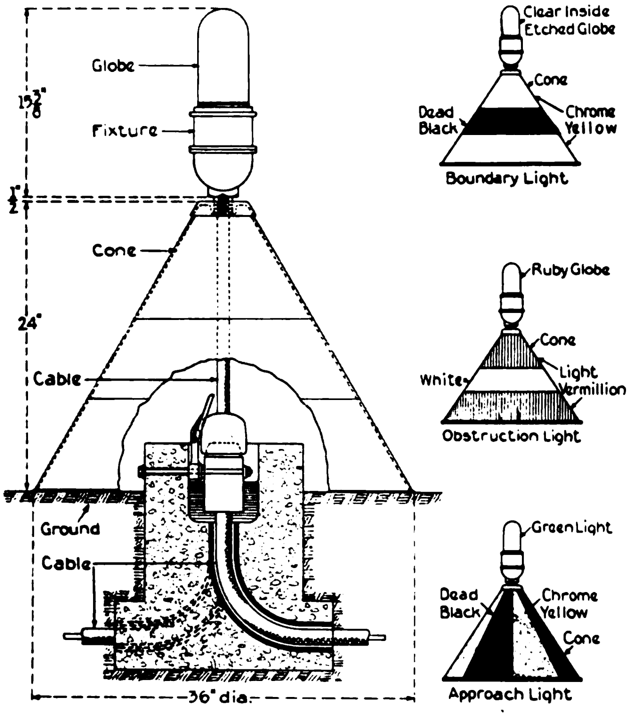

Globe
Fixture
Cone
Cable
Ground
Cable
15⅜"
1½"
24"
36" dia.
Clear Inside Etched Globe
Cone
Dead Black
Chrome Yellow
Boundary Light
Ruby Globe
Cone
White
Light Vermillion
Obstruction Light
Green Light
Dead Black
Chrome Yellow
Cone
Approach Light

Fig. 147. Improved Type of Airport Boundary Lights

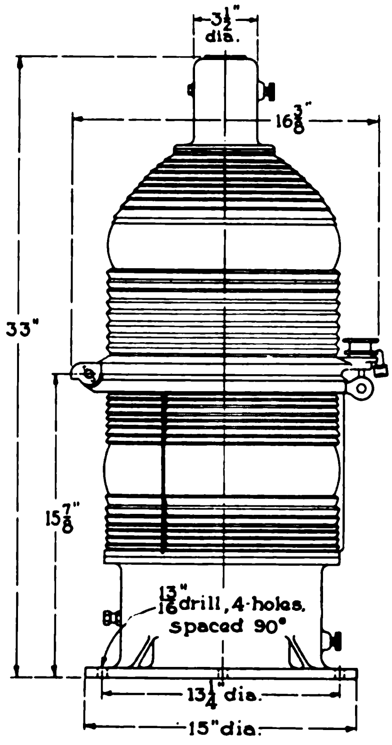

3½" dia.
16⅜"
33"
15⅞"
13/16" drill, 4-holes, spaced 90°
13¼" dia.
15" dia.

Fig. 148. Electric Code Two-lamp Beacon

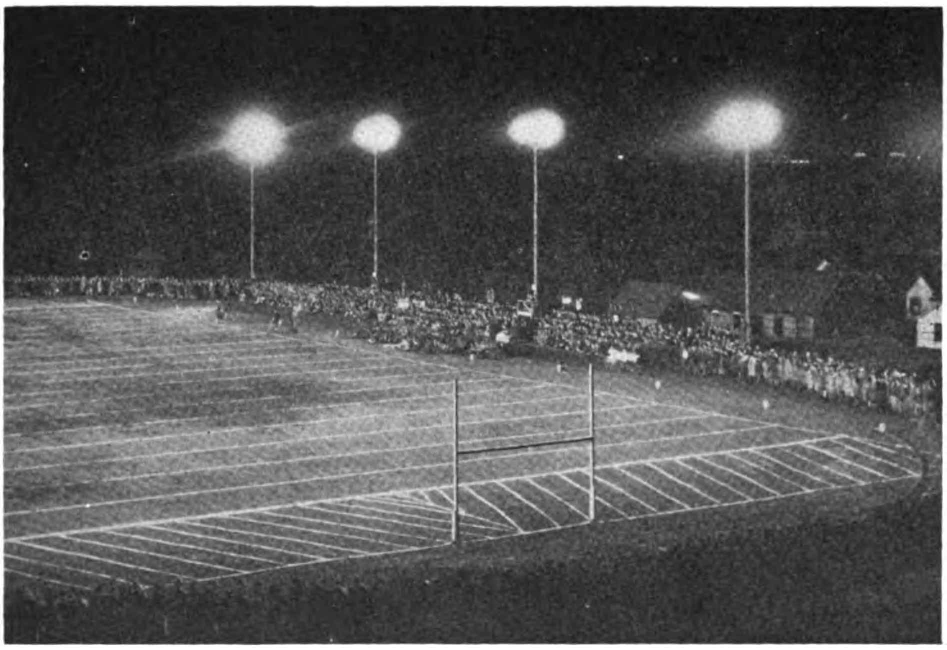


Fig. 149. A Typical Installation of Lighting Units for the Illumination of Outdoor Areas

After a careful study of all airway lighting systems, the Canadian Government adopted the standards of the United States although its beacons will be placed, for the present, at greater intervals. On-course lights (Fig. 144) will be provided, together with beacons to flash code numerals for indicating position.

The Department of Commerce changed the requirements for on-course lights from 14 to 18-in. diameter, with a 500-watt lamp. In addition to a special spherical reflector in the new lamp, it has two Fresnel lenses (Fig. 145); the larger one being 18 in. in diameter, and the smaller one being made of colored glass. The Department now uses red at isolated beacon locations to indicate no landing, and green at intermediate fields. The green on-course lights can also be used at airports.

A new design of the series-type boundary light for airports will accommodate either clear, plain, or colored globes, or large Holophane globes. These fixtures (Fig. 146) use a 60-cp. lamp for the clear globes and a 100-cp. lamp for the colored globes.

Changed requirements of the Department of Commerce on maximum voltage for the boundary circuit at airports necessitated the design of a disconnecting cutout for use with the boundary lights, this cutout having a spring cover which would close the receptacle if the boundary light and its supporting cone were knocked over or removed. The use of this cutout (Fig. 147) obviates the necessity for grounding the secondary of the constant-current transformers or the use of special transformers at each boundary fixture.

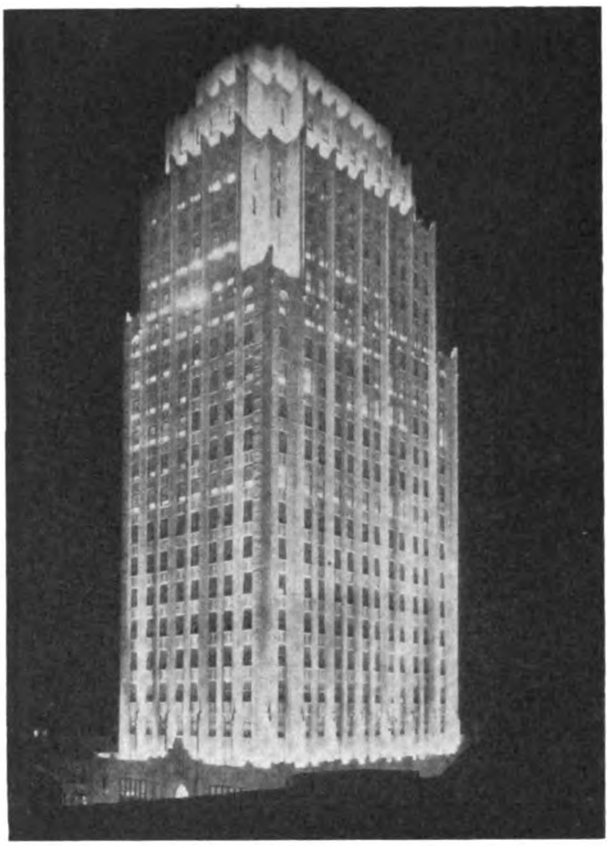


Fig. 150. Illuminated Office Building of the Pennsylvania Power and Light Company, Allentown (Pa.)

At some points on the airway, it is impossible efficiently to use the 24-in. revolving beacon, and for that reason the Department of Commerce is now installing a few electric code beacons (Fig. 148) which consist of two lamps mounted one above the other at the focal points of the Fresnel lenses. The lamps are flashed with a definite code by a separate flashing device, and are usually located on 20-ft. steel towers. These beacons are sometimes used where closer marking is required than the standard 10-mile spacing of the 24-in. revolving beacon.

Another use for the electric code beacons is for marking transmission lines crossing rivers or Government property, in which case they are flashed continuously and are provided with red color screens.

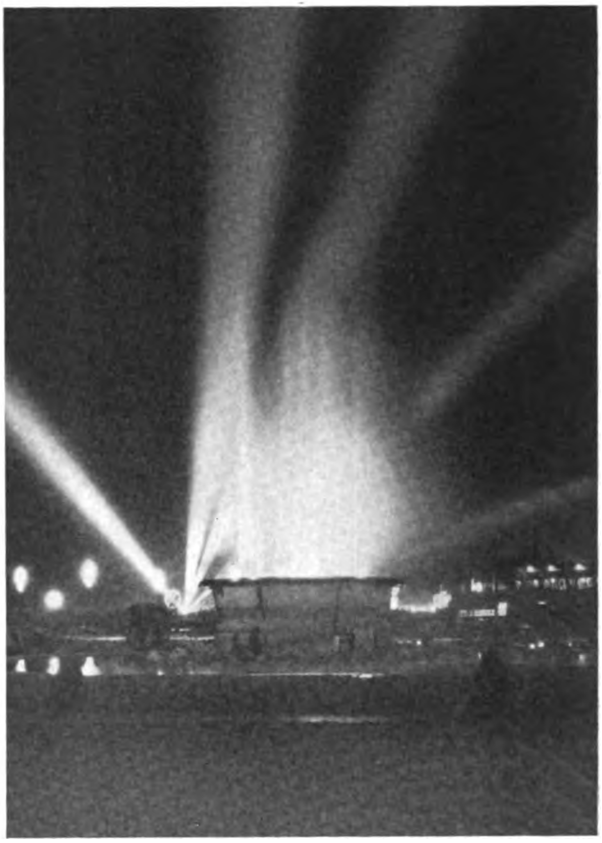


Fig. 151. An Illuminated Electric Fountain at Atlantic City (N. J.)

Floodlighting, Etc.

The use of light as a means of beautifying, advertising, decorating, and otherwise enhancing the value of public buildings, athletic fields, etc. (Figs. 149, 150, 151), continued to increase throughout the year, and in practically every section of the country.

Spectacular lighting was given an unusual impulse in the effort to secure unique decorative effects in the celebration of "Light's Golden Jubilee." In addition to the ordinary illumination by means of floodlights, there were some unusually fine examples of jeweled arches, panchromatic electric fountains, and batteries of searchlights used for scintillator effects.

Progress in Radio Receiving During 1929

By DR. ALFRED N. GOLDSMITH
Vice-President, Radio Corporation of America, New York

General Progress

IT has been a matter of astonishment to those unaware of the great potentialities of radio communication that progress along engineering and operating lines in the radio receiving field should continue at so steady a pace after nearly a decade of broadcasting development. The solution of numerous fundamental problems in radio reception in the past has still left the field open for improvements and additions which add to the artistic performance and general utility of the radio receiver.

The manufacture of radio receivers, on a large scale, using modern mass production methods has become a fairly general practice in the radio industry. This has resulted in a considerable lessening in manufacturing costs and a corresponding reduction in the price of equipment to the public. It is estimated that the prices of today are about one-half those of two years ago (for apparatus of approximately equivalent performance).

As might have been anticipated—the universal acceptance of radio receivers in the home has caused the furniture appearance aspects of such receivers to become of great importance. Cabinets which house the modern radio receiver have, therefore, been markedly improved in appearance and internal structure.

Increasing stress has been laid on high fidelity or accuracy of sound reproduction from radio receivers and upon the provision of an adequate volume of sound from the loud speakers enabling even orchestral selections to be reproduced with a satisfactory degree of realism.

The provision of ample output volume has been greatly assisted by the appearance on the market of vacuum tubes capable of giving corresponding output power (notably Radiotron UX-245). See Fig. 1.

High sensitivity in receivers may not be always utilized, but a considerable proportion of the public desires to have an extremely sensitive receiver available, on occasion, in order that comparatively weak, or distant, signals may be picked up. The introduction of the screen-grid tube has made the production of more sensitive receivers conveniently possible and, as a result, the general average of sensitivity of receivers issued during 1929 is considerably higher than during preceding years.

The excellent performance which is characteristic of the modern electric phonograph, together with the availability of the high quality electrically cut phonograph records, has contributed greatly to the renewed and increased popularity of the phonograph. It has been found that the reaction of the public to a combined radio receiver and electric phonograph outfit is favorable and, as a result, the number of such combined outfits which are finding their way into the American home is rapidly increasing.

The electric phonograph appears to supply special types of entertainment at the exact moment that they are desired; the radio receiver, in addition to the timely interest of its offerings, provides a constant succession of novel and different features. The two devices seem, in many respects, to be complementary, and their association in a single instrument is one which will probably long endure.

Broadcast transmitting stations of higher power are being installed in numerous localities to replace older and weaker stations. It is clear that the day of the one-half kilowatt "standard transmitter" is definitely past. The 5-kw. transmitter is now regarded as suitable for local service and the 50-kw. transmitter is being used with increasing frequency for high-quality service over areas of approximately 25,000 to 50,000 square miles. In certain regions which are difficult, in the radio transmitting sense, still higher powers are reasonable and to be anticipated. There is a definite tendency toward the introduction of powers as high as 500 kw. Transmitter powers of 200 kw. have been experimentally used with encouraging results.

The public and the radio industry are watching with some interest the percentage of advertising material in radio programs. Obviously, the public response to an excess of advertising material would defeat the aim of the advertiser which is, of course, the cultivation of public goodwill toward the advertised product. The appreciation of this fact by broadcasters and advertisers alike is not yet so general as is desirable, although the leading radio trade and broadcasting station associations are showing a keen interest in this subject, and in the maintenance of programs which are both artistically and technically up to the highest standards.

The public appreciation of music is undoubtedly greatly enhanced as a result of radio broadcasting. It is possible today to broadcast programs containing the more refined, unusual, or intellectual types of music with resulting satisfaction to the listeners. While popular music finds a large place in radio programs, more advanced types of music have become increasingly well-known to the public. There have been notable instances of the broadcasting of special educational concert programs to the public and also to classes in schools. The musical world has acclaimed these developments. It is noteworthy also that an increased number of orchestras of the higher grade are willing to broadcast their concerts. Orchestral leaders who hitherto have doubted whether radio broadcasting would satisfactorily place their musical offerings before the public are now "converted" and are willing to face the microphone. There have recently been organized steps dealing with the expansion and improvement in the use of radio in education. A Federal Advisory Committee on Education by Radio has been appointed and is actively functioning. It is clear that broadcasting has become appreciated as a definite and valuable agency for education.

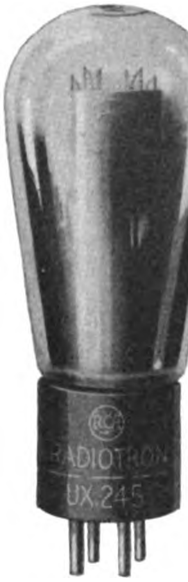


Fig. 1. Radiotron UX-245, a Power Output Tube

In quite different lines, the development of receivers in the aircraft field has gone forward rapidly during the year. Radio telegraph and radio telephone receivers are rapidly becoming standard equipment for airplanes. Radio direction-finding equipment on airplanes has been greatly improved in design as a result of extensive development and broadcasting test work.

Broadcast Receivers

Continuing the development of the tuned radio-frequency type of equipment a new receiver, using the same circuit as for Radiola 18, but with certain modifications, has been introduced (Radiola 33, Fig. 2). The changes in the circuit permit a better lining up of tuned circuits and make the operation of such a receiver relatively independent of weather conditions. Receivers of this type are mounted in a metallic cabinet. By the use of a lithographing process, the top and side panels have been finished to give the appearance of African mahogany. The adaptation of electrically and structurally suitable materials for quantity production to the type of appearance required for home use constitutes an interesting development. In order to provide increased flexibility for use in the home, receivers of this type have been furnished with or without supporting legs. The somewhat "modernistic" design of the cabinet has enabled the successful use of the receiver either as a table model or as a self-supported model.

Inasmuch as there is a well-defined need for receivers of this type in districts having a d-c. power supply, a modification of this receiver has been provided suitable for operation on 110-volt d-c. circuits. It differs from previous d-c. receivers of this model in that it is provided with a push-pull output stage.

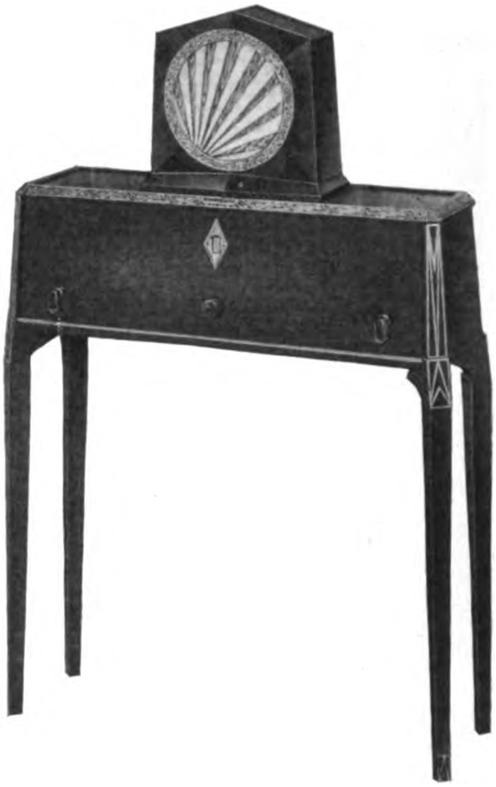


Fig. 2. Radiola 33 and RCA Loud Speaker 100-B. (Tuned radio-frequency, a-c. operated receiver with Magnetic loud speaker)

The availability of the a-c. screen-grid Radiotrons has enabled the design and commercial production of a receiving set utilizing these tubes. This receiver, which is a table model, (known as Radiola 44) and illustrated in Figs. 3 and 4, is provided with three tuned circuits, and uses two of the screen-grid tubes for radio-frequency amplification, and the third as a power detector. A single audio-frequency stage of amplification is provided utilizing the new power output tube (Radiotron UX-245).

It was found that extremely careful shielding was desirable between the various stages in order to permit obtaining the maximum usable amplification. A novel form of selector dial is employed, consisting of a rotating cut-out stencil whereby there is projected a magnified image of the tuning scale on a translucent screen in the tuning escutcheon plate. As an additional convenience in operation, concentric tuning and volume control knobs are used as well as a "local-distant switch" which enables maintaining high-quality reproduction both for strong local and weak distant stations.

Passing to a complete cabinet set of the same general type as the preceding, there has been provided a receiver (Radiola 46, Fig. 5), employing the same chassis and power unit as the preceding receiver (Radiola 44), but having in addition a dynamic loud speaker (Type 106). The power for the loud-speaker field in this case is obtained directly from the power supply unit instead of from a separate "dry" rectifier (of the copper-oxide type). All parts of this receiver are mounted in a walnut-veneer console cabinet having burled-maple overlays. It is interesting to note the attention to details which is given to furniture design in equipment of this type. Instead of the conventional loud-speaker grille and operating control board, this receiver has an embroidered silk panel which conceals the loud speaker opening and is so designed that the single tuning and volume control and its escutcheon plate appear to form a part of the pattern of the silk. Any one proposing such attention to details of artistic design five years ago would have been regarded by many members of the radio industry as unduly interested in irrelevant matters.

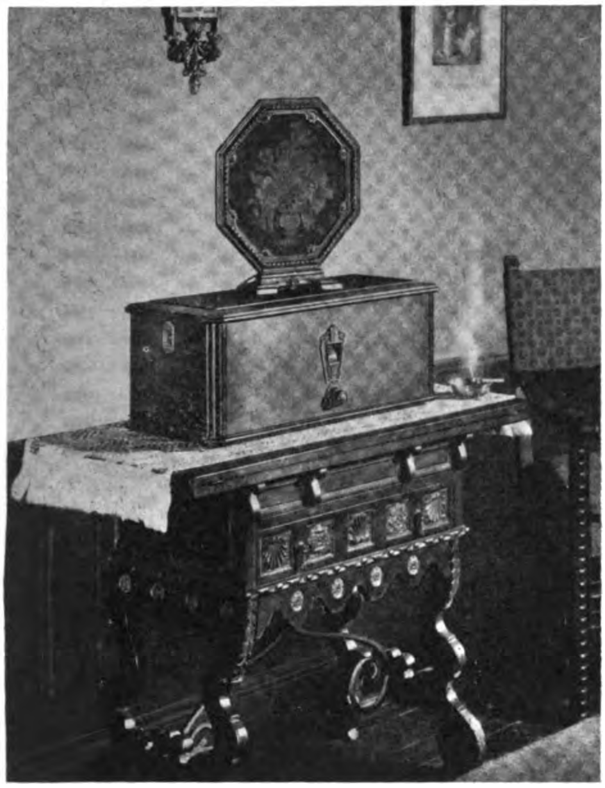


Fig. 3. A Screen-grid Tube Receiver, Radiola 44 and RCA Loud Speaker 103

This receiver is also produced in a 110-volt d-c. model which differs from the a-c. model primarily in its use of two UX-171-A Radiotrons in push-pull arrangement for the output power stage, the use of a first stage of audio-frequency amplification and a detector (utilizing UX-112-A tubes) and the employment of two UX-222 Radiotrons for the radio frequency amplifier stage. As might be expected, the chassis construction is very similar to that of the a-c. model. The same dynamic loud speaker is provided, but its field is wound for 110-volt d-c. excitation.

Combination phonograph-radio equipment having been well accepted by the public, a number of equipments of this type have been provided. One of these is a console phonograph radio receiver (Radiola 47). This is illustrated in Fig. 6; it employs a receiving set for the radio system similar to the preceding (Radiola 46) and includes an induction disk type of phonograph motor with turntable, and an electric pickup for phonographic reproduction. In this case also the cabinet is of walnut veneer, the radio controls being mounted in the center of the front, and the phonograph controls being placed in the phonograph compartment which is accessible when the cabinet lid is lifted. A record compartment is provided at one side of the top compartment. The evolution of phonograph-radio combined sets is proceeding rapidly and such outfits will probably be prominent factors in the home entertainment equipment of the future.

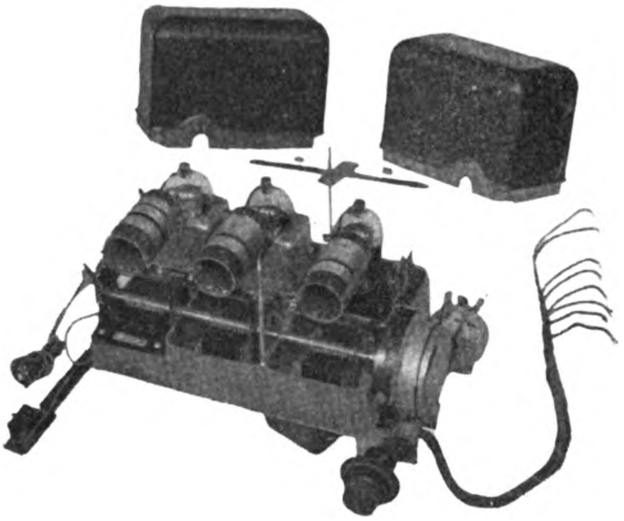


Fig. 4. Radiola 44 Chassis, Showing Screen-grid Tubes (Shielding Cans Removed)

The development of the super-heterodyne circuit has continued and it has been embodied in a form which is an improvement over that used in previous models in a later receiver (Radiola 66, Figs. 7 and 8). The improvement has made it possible to eliminate one radio-frequency amplifier tube while retaining the same sensitivity as in former models and with a higher degree of selectivity. The new power amplifier Radiotron UX-245 is used in this model, and the standard UX-280 rectifier supplies the exciting current for the dynamic loud speaker field as well as the usual voltages for the receiving tubes. The remaining tubes in this receiver are UY-227 Radiotrons.

The stencil-cut selector dial used in the screen grid model receivers is also used in this receiver, which is provided with a cabinet in two-tone walnut veneer with burled-maple overlays. The loud-speaker opening

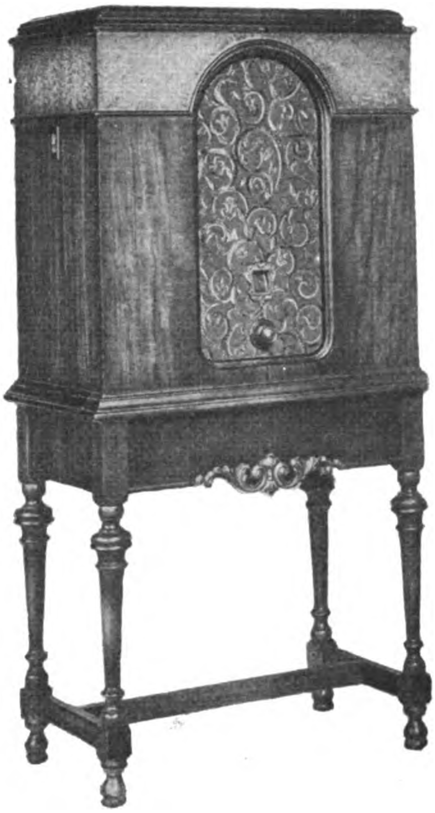


Fig. 5. Combination Receiver Using Screen-grid Tubes with Loud Speaker (Radiola 46)

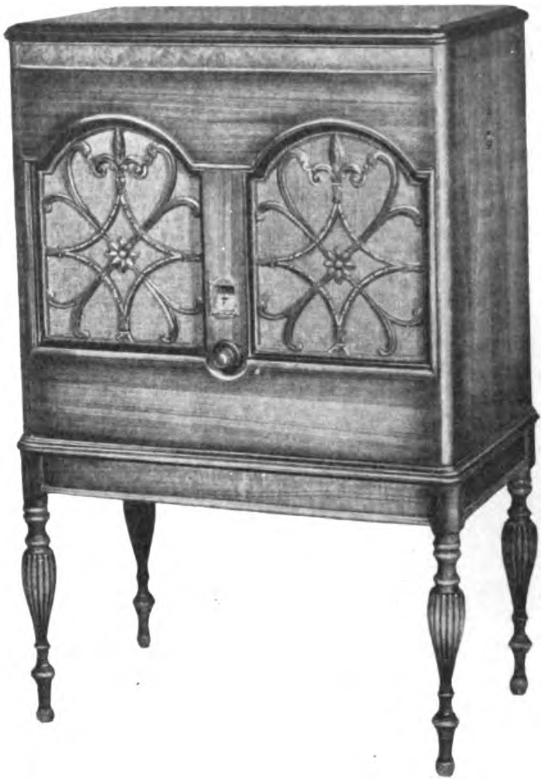


Fig. 6. Radio Receiver and Electric Phonograph (Radiola 47)

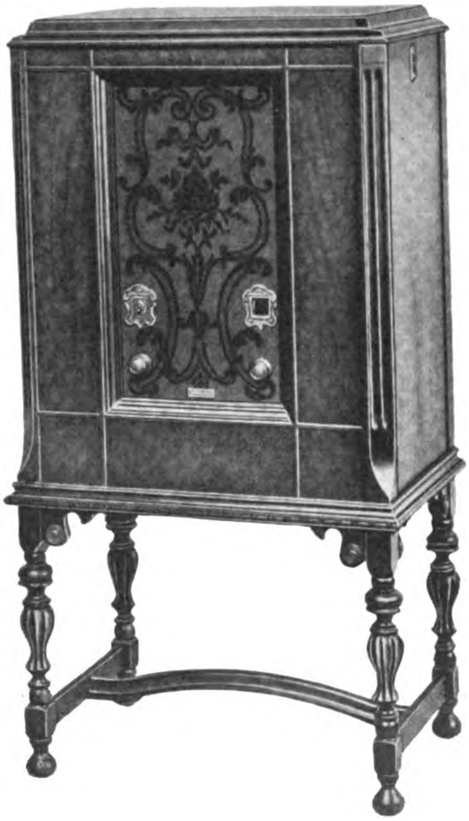


Fig. 7. Recent Superheterodyne Receiver (Radiola 66)

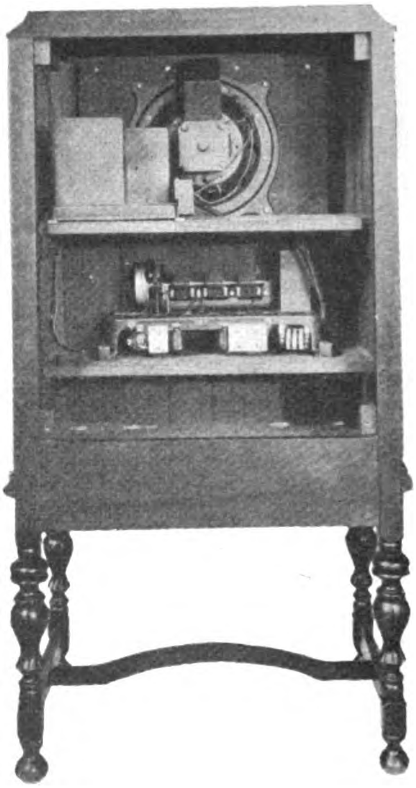


Fig. 8. Rear View Radiola 66 with Back Removed to Show Power Unit, Loud Speaker, and Receiver Chassis

and control panel are covered with an attractive piece of cut velour, the pattern in the material being chosen so as to make the controls appear a part of the design. A local-distant switch is provided and connections are available at the rear of the receiver chassis for connection to an electric pick-up for phonograph-record reproduction.

Two simple receiving sets using screen-grid Radiotrons (Radiolas 21 and 22) which are illustrated in Figs. 9 to 11, have recently appeared. The first of these is a battery-operated table model with two UX-222 screen-grid Radiotrons as the radio-frequency amplifiers and three UX-112-A tubes for the detector, first, and second-stage audio amplifiers. An alternate possibility of using a UX-171-A Radiotron for the final stage of audio-frequency amplification is provided. The filament supply in these receivers is a six-volt storage battery and the power supply is completed by the usual "B" and "C" batteries. The latter of these two receivers is a console model in a walnut-veneer cabinet, but uses the same chassis. The loud speaker Model 100-B is included in the cabinet which also houses the necessary batteries.

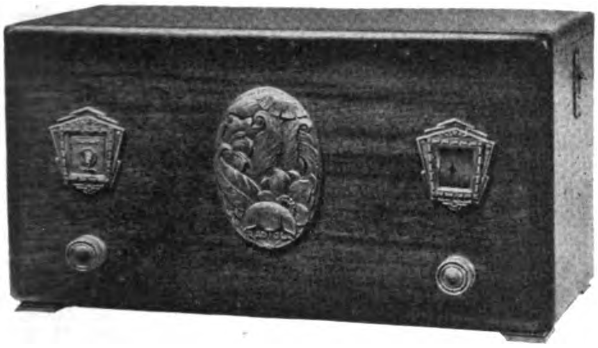


Fig. 9. Simple Screen-grid Tube Receiver (Radiola 21)

A decidedly different type of receiver is the Victor-Radio console (Model R-32). This model is illustrated in Figs. 12 to 16. The distinctive features are a new mechanism for lining up the variable condensers, together with the mechanical system used for rotating these condensers which makes possible a full-vision tuning scale. Four tuned radio-frequency stages of the Rice neutralized type, utilizing five UX-226 Radiotrons, form the radio-frequency amplifying system. A UY-227 tube is used as a detector and a UX-226 as a first-stage audio amplifier. The output stage consists of two UX-245 power Radiotrons in a push-pull arrangement, and a UX-280 tube is employed as a rectifier. The arrangement of parts in this receiver includes the placement of the chassis at the top of the cabinet with the controls at the top center of the front panel. The loud speaker is mounted at the center in the bottom of the cabinet with a power unit beside it.

A modification of this receiver known as Model R-52 and shown in Figs. 17 and 18, employs the same equipment but is housed in a more elaborate cabinet. Double doors are provided to cover the front panel and these may be swung back against the sides of the cabinet when the receiver is in use, this being a feature of considerable aesthetic value and operating convenience.

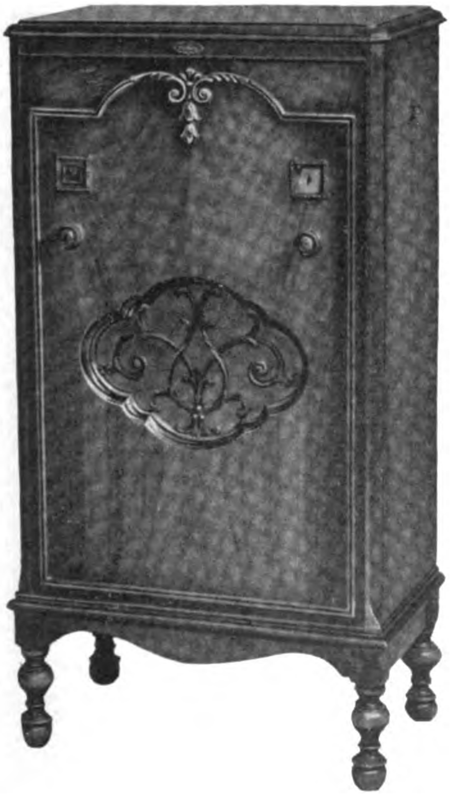


Fig. 10. Front View Radiola 22. Combined screen-grid tube receiver and loud speaker

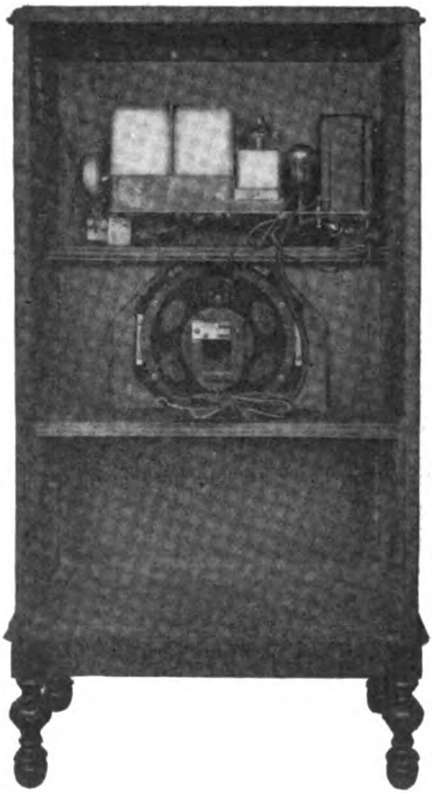


Fig. 11. Rear View Radiola 22 with Back Removed to Show Receiver Chassis and Loud Speaker

The front doors have inlaid medallions of matched butt walnut and the body of the cabinet is of American walnut with inside panels of bird's-eye maple. This summary of recent radio progress indicates the increasing stress which is being laid upon the careful selection of woods or other structural materials in order to adapt successfully receivers to home conditions.

An unusually complete type of receiver of exceptionally advanced operating characteristics has

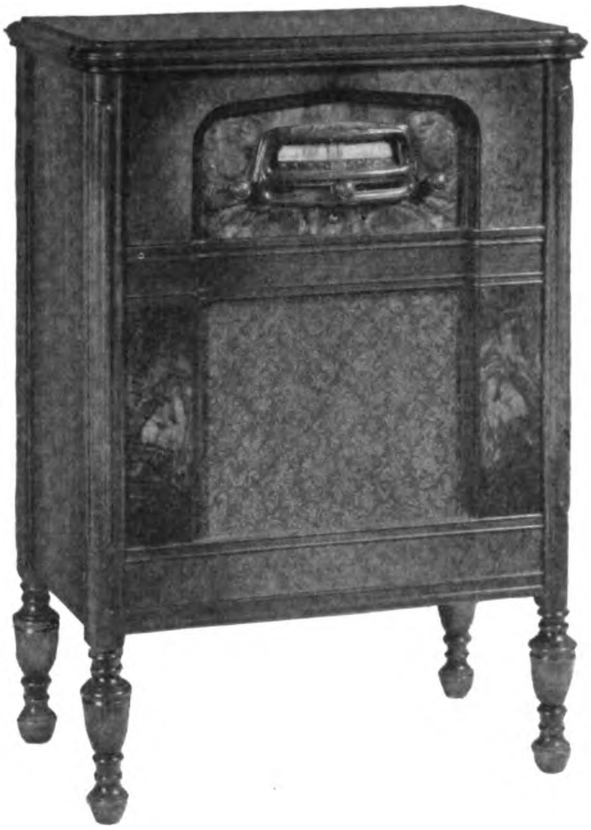


Fig. 12. Tuned Radio-frequency Receiver (Victor Model R-32)

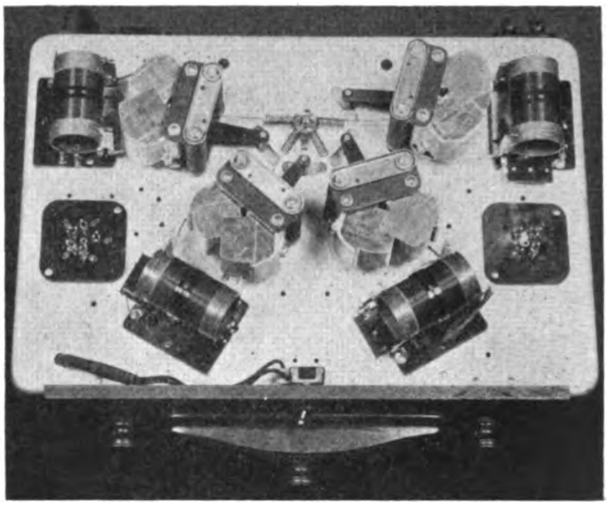


Fig. 14. Bottom View of Chassis of Victor Receiver R-32, with Cans Removed

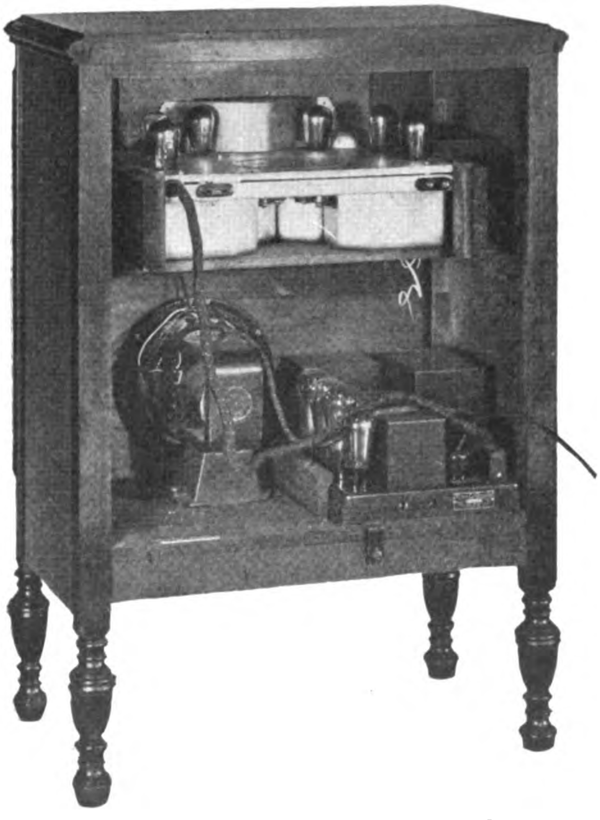


Fig. 13. Rear View Victor Receiver, Model R-32, Showing Receiver Chassis, Loud Speaker, and Power Unit

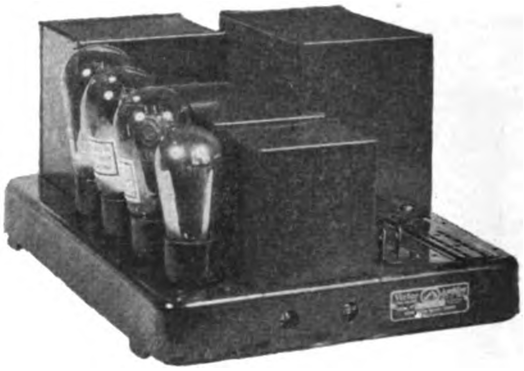


Fig. 15. Victor Receiver R-32 Amplifier

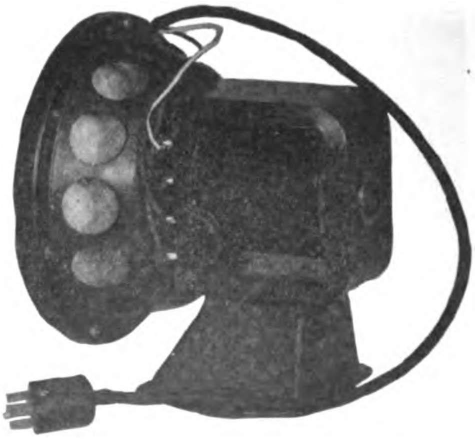


Fig. 16. Victor Receiver R-32 Loud Speaker

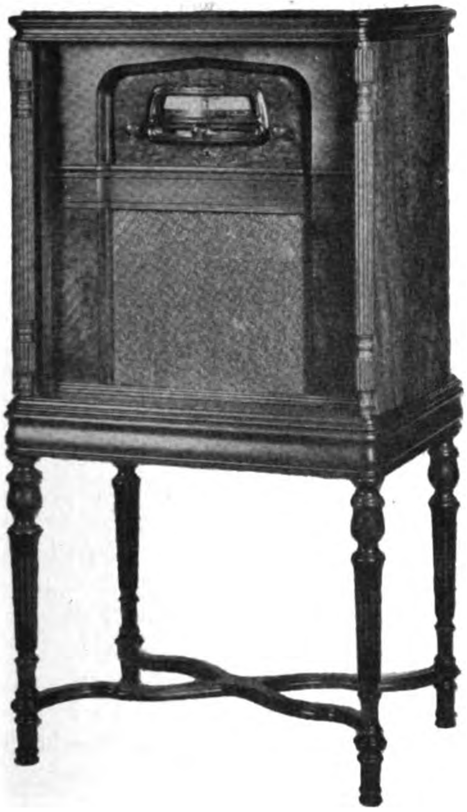


Fig. 17. Victor Receiver R-52

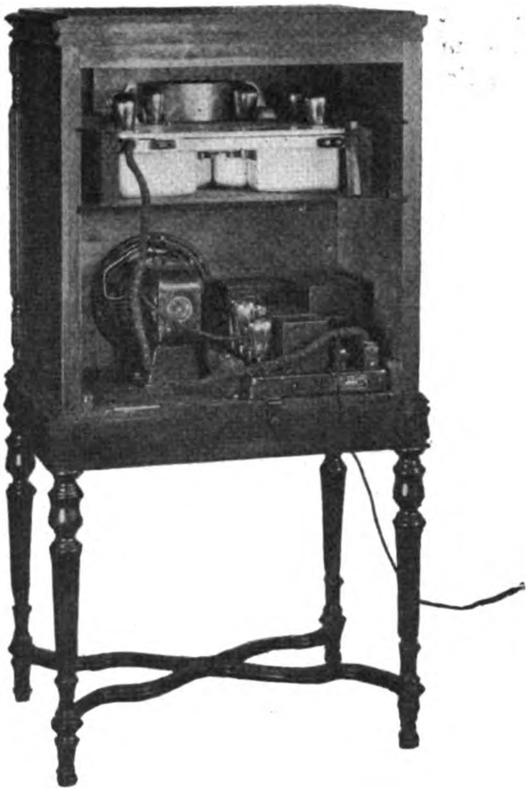


Fig. 18. Rear View Victor Receiver, Model R-52, Showing Receiver Chassis, Loud Speaker and Power Unit

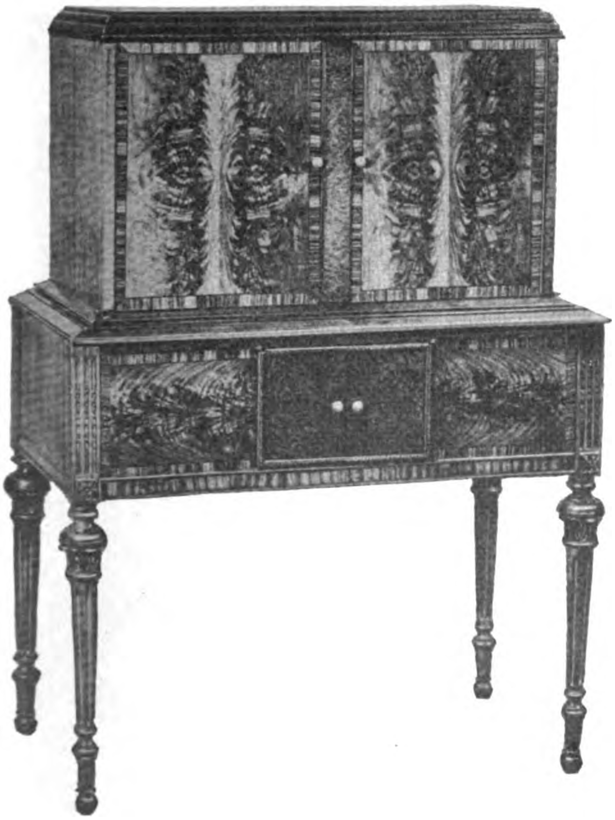


Fig. 19. Superheterodyne Receiver with Automatic Volume Control and Tone Control (Radiola 67)

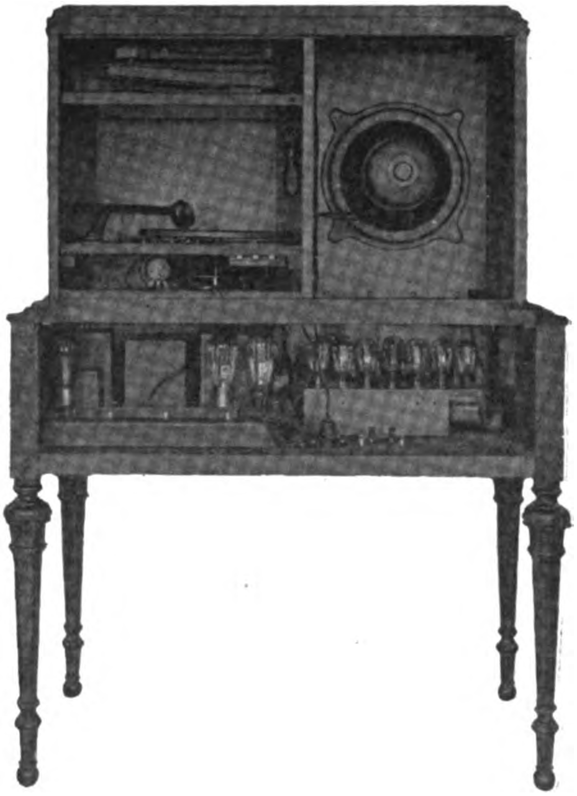


Fig. 20. Rear View Radiola 67 with Compartment Backs Removed to Show Phonograph, Loud Speaker, Receiver Chassis, and Power Unit

appeared recently (Radiola 67, Figs. 19 and 20). The walnut cabinet is also an outstanding feature of this model. Inlays of satinwood and rosewood with panels of burled walnut and crotch mahogany make this an outstanding piece of furniture. The lower part of the cabinet contains the receiver chassis and power-supply unit, and two small doors are arranged to cover the small radio control panel which is in the center of the lower part of the cabinet. After the station tuning has been completed these doors may be closed so as to hide the tuning controls if desired. The upper portion of the cabinet is divided into two halves, the right containing the phonograph compartment, with its controls on a small panel below the turntable board, and the left containing the loud speaker. The large doors on the two upper portions of the cabinet are arranged to swing back against the sides of the cabinet.

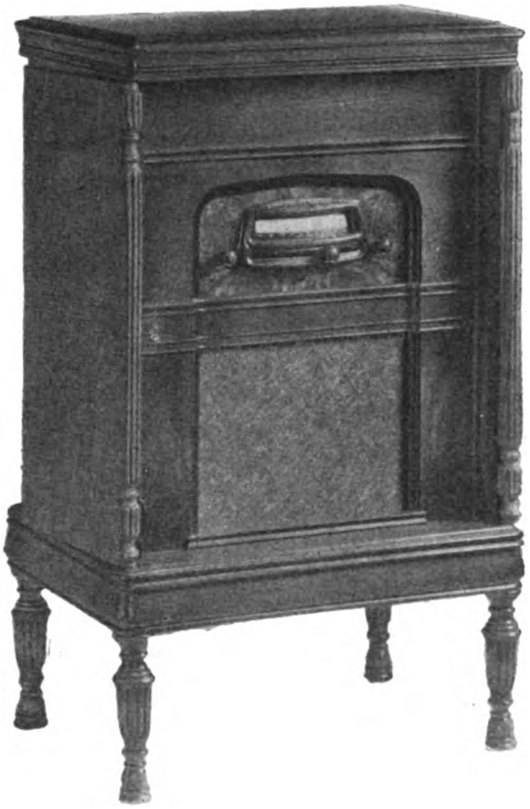


Fig. 21. Receiver and Electric Phonograph (Victor Model RE-45)

Another combined radio receiver and electric phonograph has also been placed on the market recently (the Victor Radio Electrola RE-45). (See Fig. 21). This model is mounted in a somewhat larger cabinet than the R-32 and includes phonograph equipment in addition to the radio equipment. The cabinet of this model differs further from the R-32 model in being supplied with doors which may be swung back against the sides of the cabinet. The phonograph turntable, together with its controls, is mounted in a horizontal panel at the top of the cabinet and is reached by lifting the hinged top of the cabinet. Compartments at each side of the motor board provide space for phonograph records. A switch operated by a knob at the right side of the tuning dial of the receiver provides means for quick changeover from radio to record reproduction. On the opposite side of the tuning dial, symmetrically placed, is the volume control for the radio receiver.

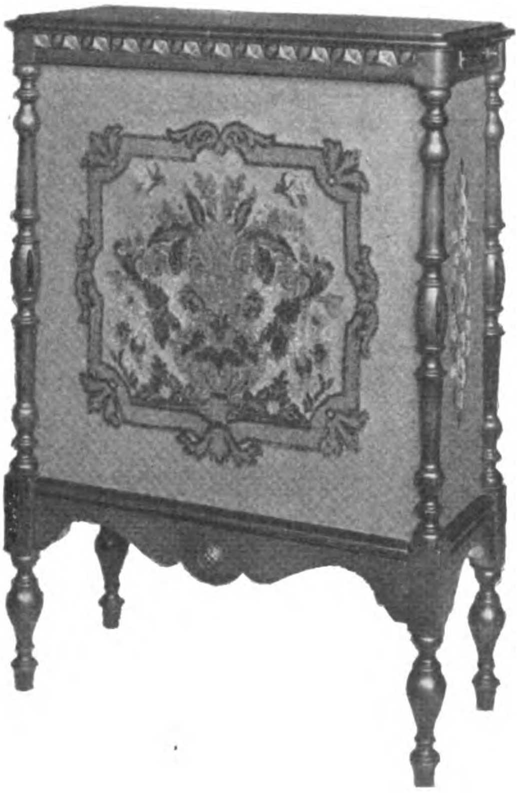


Fig. 22. Dynamic Cone Loud Speaker

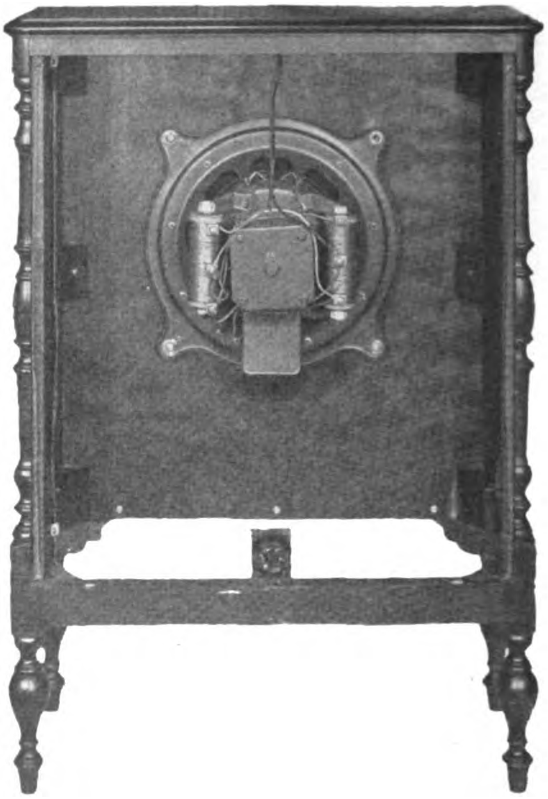


Fig. 23. Rear View of Dynamic Cone Loud Speaker (Back Removed)

Loud Speaker

A cabinet type of "dynamic cone" loud speaker, representing a development of previous forms, was made available during the year (Model 106). This loud-speaker includes a "dry rectifier" for field magnet current supply, the rectifier being mounted on the loud speaker frame. It is illustrated in Figs. 22 and 23.

The whole is surrounded by a walnut cabinet covered by a specially woven velour having a harmonious color pattern of suitable dimensions for the sides and front of the cabinet. The back of the cabinet is an open woven grille, the bottom of the cabinet is open, and the cabinet itself is shallow. The resonance effect of the cabinet is thus minimized. This model is built to operate on 110-volt a-c. supply.

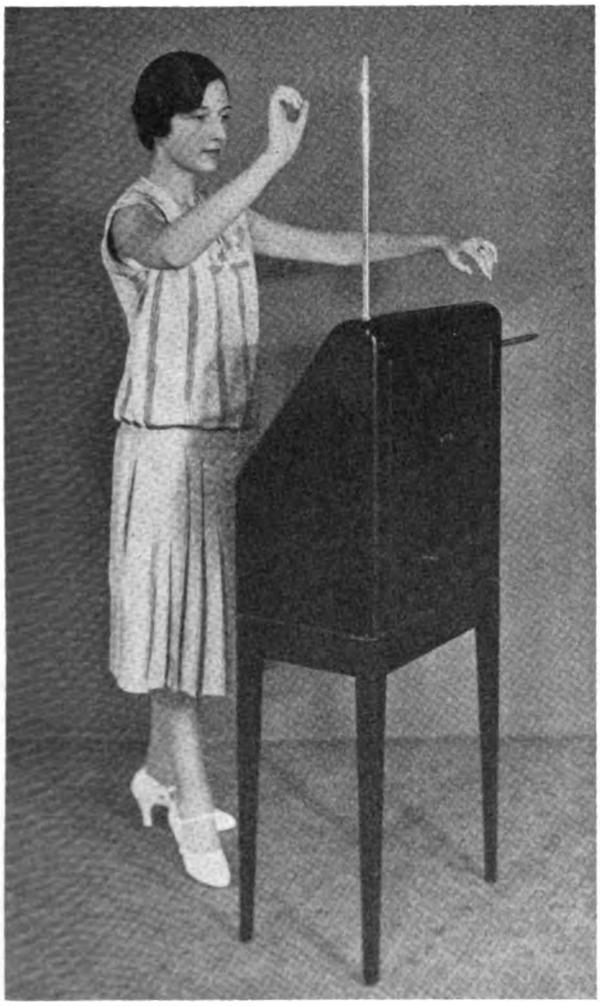


Fig. 24. RCA Theremin (Electric Musical Instrument), Showing Correct Playing Posture

Centralized Radio Equipment

Two different systems of apparatus for different classes of service are available in centralized radio equipment. One is known as the audio-frequency system and the other as the radio-frequency system. Both systems have met with very great favor and demand during the year, and many installations are in progress in all parts of the country. These two systems provide perfect solutions of the radio-reception problem for large buildings of all types, including apartments and hotels as well as public institutions of all sorts.

Various new pieces of apparatus have been added to the line to complete the service rendered by these equipments. These items are devices such as the automatic electric phonograph, group switches for controlling all extensions from a central location, an improved super-heterodyne receiver with automatic volume control, and the like.

RCA Theremin Musical Instrument

To the production of music three individuals must contribute: the instrument maker, the composer, and the interpretive musician. Little research has ever been applied to the improvement of the standard musical instruments of the mechanical type, and for decades no radical changes have been made. Music as an art cannot attain the full growth of which it is capable unless fostered and nurtured by science. The art of stage illumination did not exist before the scientific researches of laboratories on electric lighting. The art of communication took long steps forward with the invention of the telegraph, telephone, and radio telegraphy. The music life of the world was tremendously broadened by the perfection of radio broadcasting transmitters and receivers.

The RCA Theremin (named after its inventor, Professor Leon Theremin) is an instrument which produces musical sound without keyboard, strings, reeds or other mechanical aids or sources of sound. (See Fig. 24). It enters the field of musical instruments as one generating musical tone by electrical methods, a system which combines simplicity of operation, uniformity of tone color, and the possibilities of unlimited volume. It employs a loud speaker, a chassis for radio-frequency oscillators and audio-frequency amplifying system, and two metal rods as antennas, one controlling pitch and the other controlling volume. When any object, such as the human hand, is brought into the electrostatic field surrounding the vertical antenna, the field is so affected as to change the audible beat frequencies produced which are amplified and applied to a loud speaker. The volume-control antenna field is also affected by the proximity of a hand, controlling the sound intensity from a faint whisper to any desired higher volume.

Not only does this instrument mark the introduction of electricity into the field of musical instruments, but scientists and musicians of note and of standing have gone on record with their opinions that the RCA Theremin is likely to revolutionize the whole world of music.

In any case, this instrument, in addition to its musical capabilities, demonstrates in spectacular and convincing fashion the superior capabilities and flexibility of electrical modes of music production. The mysterious nature of electrical forces cannot be better exemplified than by an instrument whereby music is literally evoked from the air. It also marks a fundamental departure in that radio, through it, is contributing toward the creation of music as well as its reproduction.

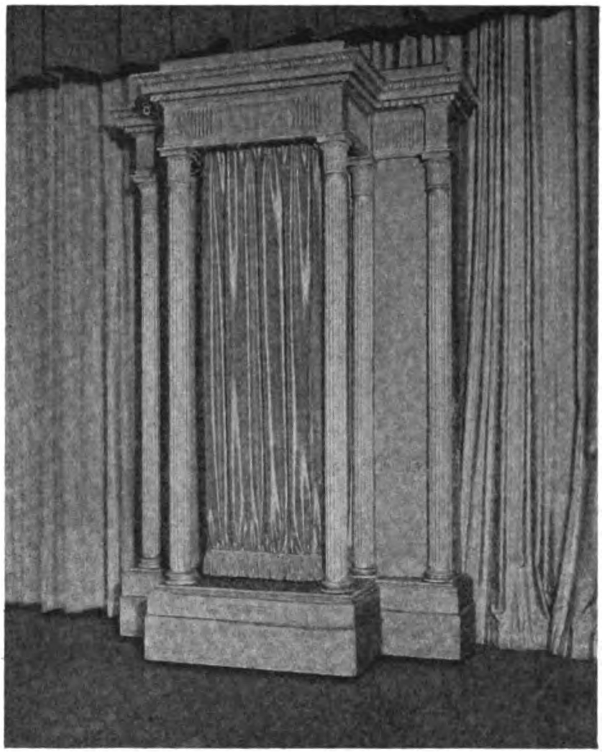


Fig. 25. Auditorium Radiola Loud Speaker

Receiver-phonograph Combination for Auditorium Use

This instrument and its attendant auditorium loud speaker have been produced primarily for educational and entertainment use in school auditoriums. (See Fig. 25.) They may also be used, however, wherever it is desired to provide radio or phonograph programs for any large indoor assemblies. The radio system corresponds essentially to that of the Radiola 66, and in addition an extra stage of audio power amplifier, using two UX-250 Radiotrons in push-pull is provided. Separate "dry rectifier" field supply for the three dynamic loud speakers is provided, and the phonograph equipment is similar to that used in the Radiola 47. Both the console cabinet and the auditorium loud speaker unit are finished in antique ivory. They are shown in Fig. 26. The loud speakers are mounted in an ornamental baffle constructed to resemble in miniature the front of an ancient Greek temple.

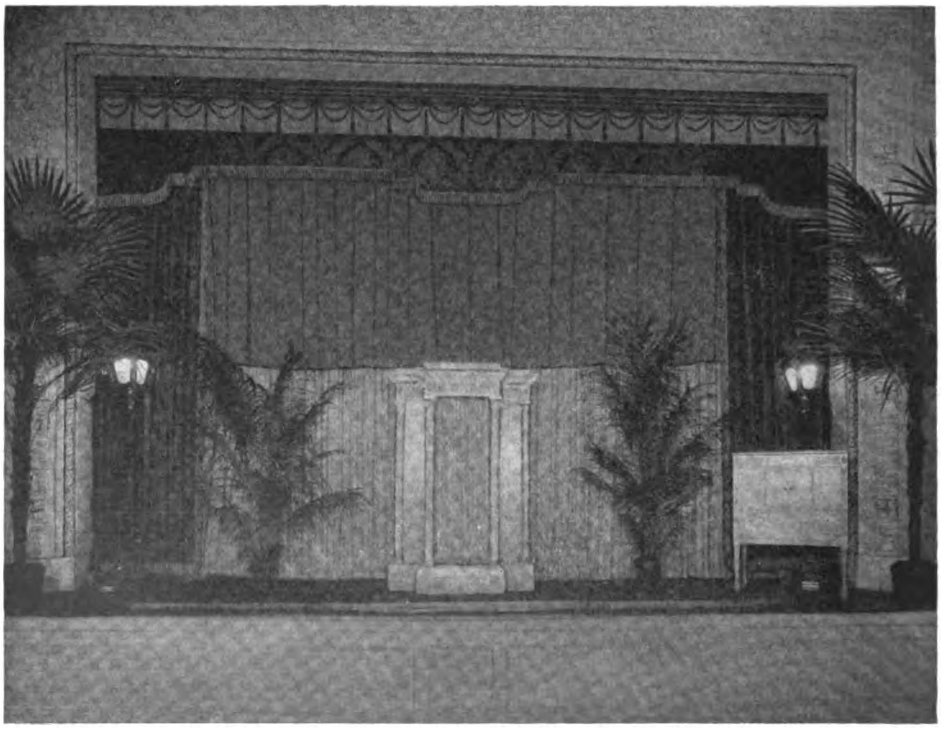


Fig. 26. Auditorium Radiola Loud Speaker and Console

To the usual performance characteristics of the Radiola 66 this model adds the necessary large volume output needed for auditorium reproduction purposes. A monitoring jack is provided for listening to the output of the power amplifier with a pair of head phones while the loud speaker is silent. This is useful in tuning in a radio program. A lock is provided for the lid of the cabinet, and arrangements are made so that this automatically locks the other openings of the cabinet.

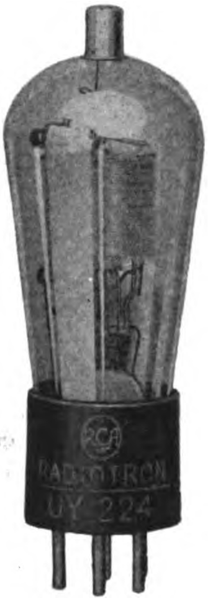


Fig. 27. Radiotron UY-224

Vacuum Tubes Introduced During 1929

The first of these is a screen-grid tube (Radiotron UY-224) which is designed for operation on an alternating-current supply. This is shown in Fig. 27. In the short time it has been on the market it has achieved great popularity, and indications are that it will occupy a very important position in radio design in the future.

A new power amplifier tube known as Radiotron UX-245 has appeared necessary which has power-handling capacity midway between those of the UX-171-A and the UX-250. An outstanding feature of this tube is the relatively low plate voltage required for maximum output. This tube is relatively low-priced, and, because of its low plate voltage requirement, can be used in medium-priced receivers.

Sound Motion Picture Equipment

The sound motion picture art has progressed with amazing rapidity during 1929. The technique of this difficult art has reached the point where the public reaction is one of increasing acceptance and stabilized patronage. The production of sound motion pictures has centered in Hollywood, with a secondary producing center in New York. Some idea of the appearance of a recording studio can be gained from the accompanying illustration (Fig. 28) of a section of one of the stages of Gramercy Studios of RCA Photophone, Inc., in New York. The microphone, the recorder booth, and certain of the sound-proofing equipment are visible in this illustration.

Reproducing equipment has been increasingly simplified during the year. It can now be comfortably installed in ordinary projection rooms, will operate with either film or disk records, has a high degree of reliability under service conditions, and is in a price range which is acceptable to the average theatre owner. The stage arrangements are of increasing simplicity, and the amplifying equipment resembles fairly closely that used in the higher-grade broadcasting stations. Special equipment (Type E or semi-portable sound-reproducing and projecting equipment of the RCA Photophone Industrial and Educational Division) is available for auditorium and other non-theatrical uses. The spread of the sound motion picture is so rapid that a silent picture, except for certain special uses, will be rather an oddity within the next few years. The adaptation of radio broadcasting technique to this newest division of electrical engineering is an interesting example of scientific evolution and adaptation.

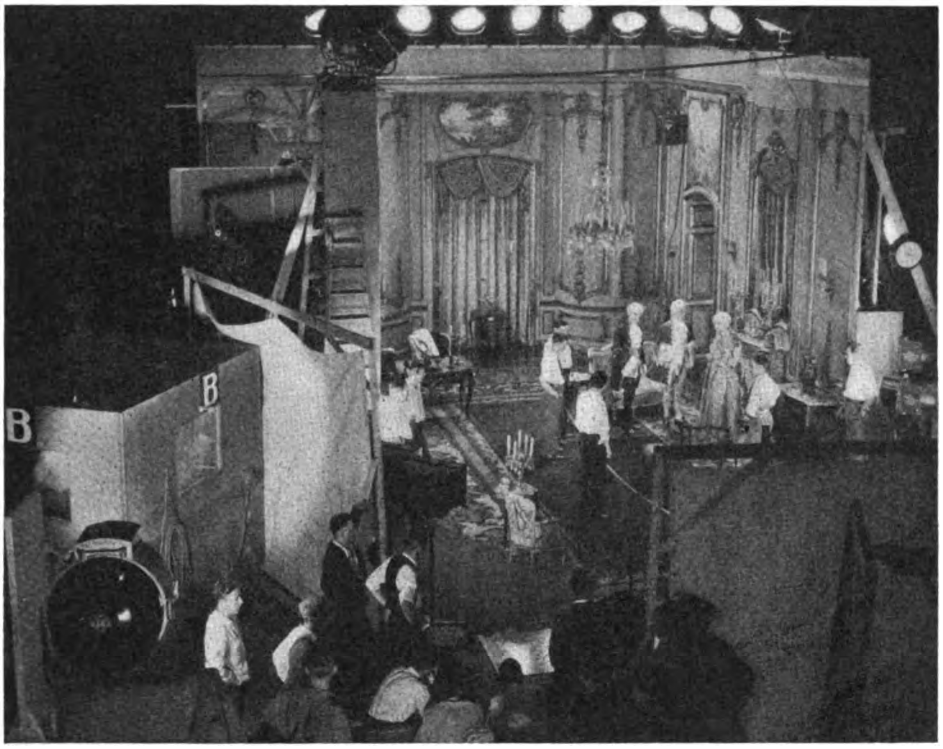
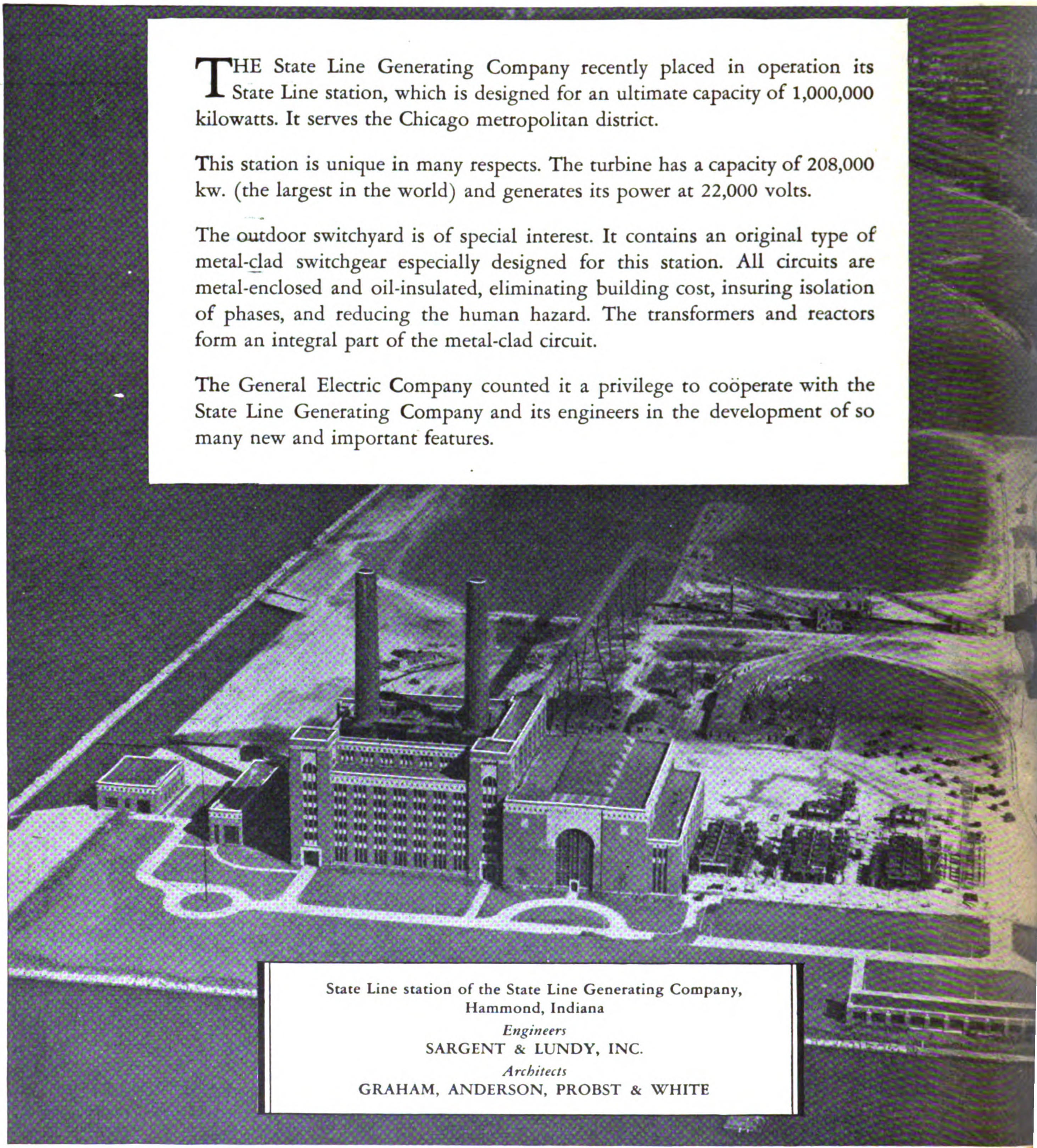


Fig. 28 Recording a Talking Picture at the Gramercy Studios of RCA Photophone in New York City. The microphone which picks up the speech of the players may be seen suspended from the black box shown in the upper right of the setting, directly to the right of the chandelier. In the left foreground is one of the many sound recording booths of the studio to which the speech impulses picked up by the microphones are carried for recording on the film

ACHIEVEMENTS AT



THE State Line Generating Company recently placed in operation its State Line station, which is designed for an ultimate capacity of 1,000,000 kilowatts. It serves the Chicago metropolitan district.

This station is unique in many respects. The turbine has a capacity of 208,000 kw. (the largest in the world) and generates its power at 22,000 volts.

The outdoor switchyard is of special interest. It contains an original type of metal-clad switchgear especially designed for this station. All circuits are metal-enclosed and oil-insulated, eliminating building cost, insuring isolation of phases, and reducing the human hazard. The transformers and reactors form an integral part of the metal-clad circuit.

The General Electric Company counted it a privilege to coöperate with the State Line Generating Company and its engineers in the development of so many new and important features.

State Line station of the State Line Generating Company,
Hammond, Indiana

Engineers
SARGENT & LUNDY, INC.

Architects
GRAHAM, ANDERSON, PROBST & WHITE

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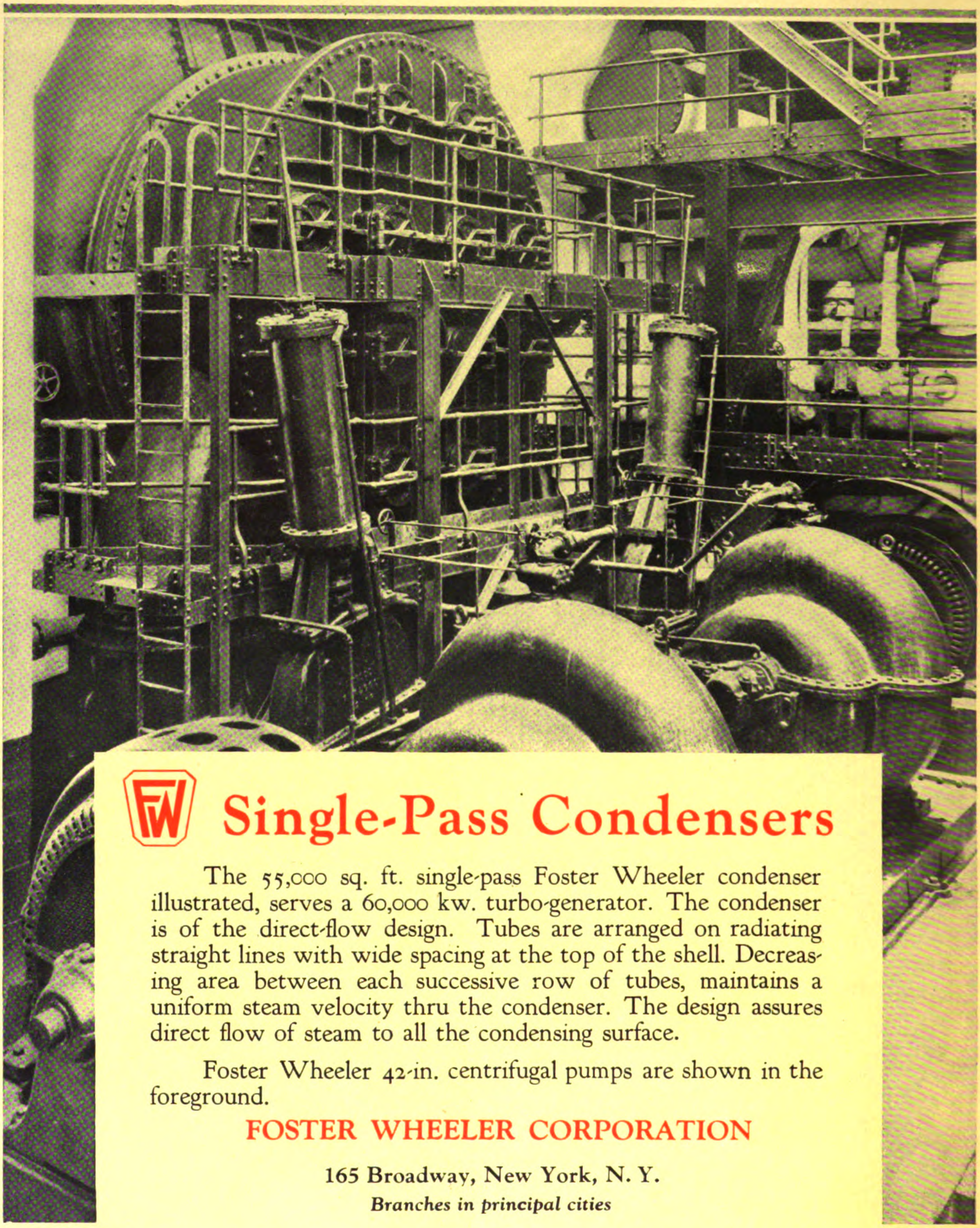
GENERAL ELECTRIC REVIEW

VOL. 33, No. 2 FEBRUARY, 1930

"OUR OLD ENEMY—LIGHTNING"
A photograph taken from the East Shore of Pontoosuc Lake, near Pittsfield, Massachusetts

In This Issue: *Melioration by Matter* *Simulating Sunlight* *Substation Ventilation*
Transformer Testing *The Three-phase Arc Furnace* *Effect of Corona*
Electric Drive for Light Vehicles *A Curious Phenomenon* *Thyrite Lightning Arresters*



Single-Pass Condensers

The 55,000 sq. ft. single-pass Foster Wheeler condenser illustrated, serves a 60,000 kw. turbo-generator. The condenser is of the direct-flow design. Tubes are arranged on radiating straight lines with wide spacing at the top of the shell. Decreasing area between each successive row of tubes, maintains a uniform steam velocity thru the condenser. The design assures direct flow of steam to all the condensing surface.

Foster Wheeler 42-in. centrifugal pumps are shown in the foreground.

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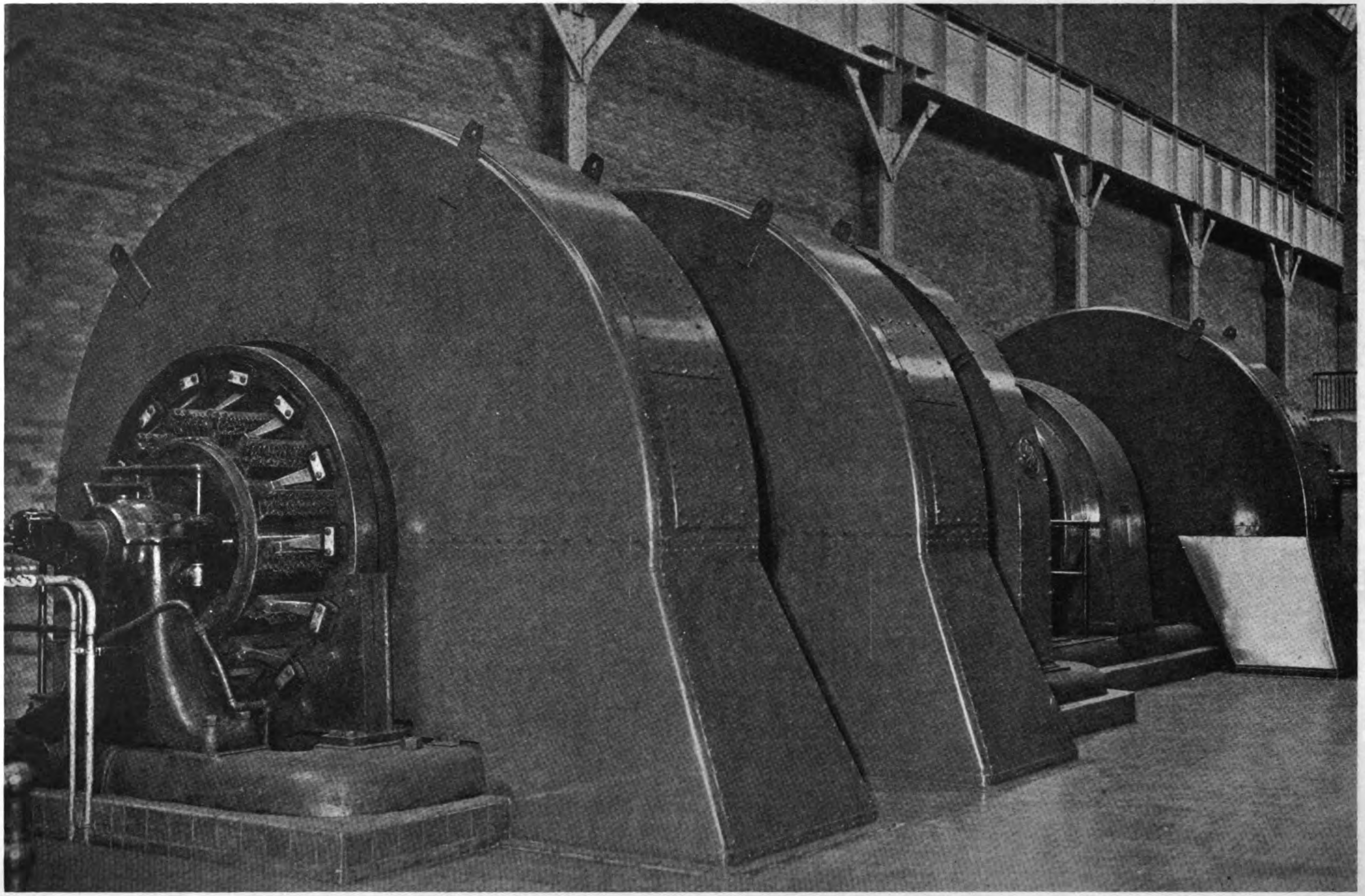

THE MOST EFFICIENT UTILIZATION OF WINDAGE LOSSES

The windage of electrical machines is now being directly applied to building ventilation, as well as to cool the machines themselves. This steel-mill flywheel motor-generator set consists of three 2400-kw. generators driven by a 5000-hp. induction motor. The d-c. machines are enclosed in blower scrolls and the a-c. in a concentric housing. The incoming air after being heated by the losses of these machines is directed by the enclosing housings into ducts which discharge it outside the building (p. 104)

GENERAL ELECTRIC
REVIEW

Vol. 33 February, 1930 No. 2

LIGHTNING

After reading Dr. Whitney's Founders' Day address at Lehigh University and an article by Mr. K. B. McEachron on Thyrite, a new form of lightning arrester material (both published in this issue), we thought how well the production of Thyrite exemplifies the kind of materialism that is so common in the world today. Needless to say, we do not number ourselves among those who deplore materialism. Materialism of the right sort is just what is everlastingly leading us to making new and useful things and making us think new and useful thoughts.

Since the beginning of time we have had thunder and lightning. Primitive man looked upon the lightning as the wrath of God and the rumbling noise as the thundering of His mighty voice in displeasure at man. Heathen mythology, with its exquisite poetical fancy and lively imagination, personified, symbolized, and deified the natural phenomena witnessed all around. Thus Jupiter Fulminator hurled the lightning bolt to slay impious men! Ajax defied the lightning! But who was "materialistic" enough in those days to try to protect man's handicraft from the ravages of lightning?

Lightning plays many freaks and so does history. King Solomon, with all his wisdom, unknowingly did better than even *he* knew. History has many curious and interesting cases of man's work exceeding the knowledge of his age, but where can a more interesting example be found than when King Solomon, the son of David, the Psalmist, built "an house for the name of the Lord"?

For centuries it was the boast of the Jews that although Solomon's temple stood on high ground and all the structures around and about it had been struck by lightning at one time or another, King Solomon's temple had never been struck. But why? Let us take a few fragmentary quotations from that beautiful description of the building of Solomon's temple given in the second book of Chronicles: "And the porch that was before the house . . . . . He overlaid it within with pure gold. And the greater house he ceiled with fir trees which he overlaid with fine gold and wrought thereon palm trees and chains . . . . He overlaid also the house, the beams, the thresholds and the walls thereof and the doors thereof with gold . . . . . And he made the most holy house . . . and he overlaid it with fine gold amounting to six hundred talents and the weight of the nails was fifty shekels of gold . . . And he overlaid the upper chambers with gold."

All the wisdom of our modern scientific and technical knowledge could not protect a building better!

The history of man's efforts to protect his structures from lightning is long and interesting. Many old conceptions have been disproved—many new theories have been proved useful. We know today, contrary to ancient belief, that neither lightning nor thunder, terrifying as they are, is the cause nor even the controlling factor in producing storms. Thunderstorms are not even caused by the free electricity in the air. Some day someone should write a book on the Mechanism of a Thunderstorm; for although our knowledge is far from complete, the phenomenon is becoming better understood all the time.

Old Flammarion tells us that a Dr. Wall about 1650 was the first to compare lightning with the tiny spark he produced by rubbing a cylinder of amber, and the sharp noise with thunder; but it was not before Franklin's classical experiment of June, 1752, that the identity was established beyond doubt. Since this identification of the "bolt from the blue," being the same entity as the electricity with which we can experiment in our laboratories, much has been done to give us a better understanding of lightning.

It is interesting to look upon our world itself as a fabulously large electric machine. Imagine a globe nearly 8,000 miles in diameter, partially surrounded by oceans of water and entirely surrounded by an ocean of atmosphere. Even if we think of our atmosphere as extending above the earth for a greater distance than we have examined, there is no probability of storms or clouds occurring as high as six miles above the mean level of our oceans.

For our purpose, we can look upon the vertical rays of the tropical sun as forming the largest pump in existence. It is a fine example of perpetual motion as it is raising water from the ocean all the time and distributing it over the greater part of the earth's surface.

Each 24 hours, this gigantic pump raises 300 cubic miles of water which means that 16 million tons of water fall to the earth's surface every second. This water in its ascent, its travels, and in falling is acted upon by such conflicting forces and goes through so many changes of form that it would take volumes to tell the story. All these occurrences take place in a layer, or stratum, less than six miles around the earth's surface. The clouds, the wind, and the water in this thin layer form a huge electric generator. The magnitude of this machine can best be described by quoting data collected by the British Meteorological Office.

The data show that at any one time there are about 1800 thunderstorms in progress around the world and that the average number of lightning flashes during a storm is about 200 per hour. In other words, there occur about 100 flashes per second if we consider the total lightning discharges going on around the world at all times.

The *Encyclopedia Britannica*, quoting Humphrey, the author of *Physics of the Air*, states: "The field developed at the earth's surface in the vicinity of thunderclouds is in order of 100,000 volts per meter, and an average lightning flash may discharge about 20 coulombs through a length of two kilometers."

The mechanism of how electric generation takes place in the clouds makes a fascinating story. Our old physicists used to love to visualize and talk about freezing, and thawing, and air friction as the causes; but now we know that all their pictures were wrong.

It was the classical researches of Dr. G. E. Simpson of the Indian Meteorological Department which were carried out at Simla in 1908-1909 that have given us the most tenable theory.

By means of an automatic-tipping rain gauge and a self-registering electrometer he proved among many other things: (1) that the electricity brought down by rain is sometimes positive and sometimes negative; (2) that the quantity of positive electricity was 3.2 times the quantity of negative electricity brought down; (3) that the period during which positively charged rain fell was 2.5 times longer than the time during which negatively charged rain fell. We have quoted only three of Dr. Simpson's twelve major observations of the electrified state of rain.

Dr. Simpson carried out many other marvelously well-devised experiments to determine the electrical effect of each of the well-known factors that go to make up a thunderstorm. Perhaps the most striking of these was to allow drops of distilled water to fall through a vertical blast of air of such strength as to produce some spray. These experiments proved the all-important facts that the breaking up of drops of water produces both positive and negative electricity and that three times as many negative ions as positive are released, which leaves the drops positively charged.

Here is the key to understanding the mechanism of a thunderstorm. But unfortunately we have to be brief, so we must ask our readers to remember that extreme accuracy must be sacrificed for brevity.

Who hasn't lost himself in admiration sometimes at the beauty of those great woolly-looking cumulous clouds? Sometimes they are three miles thick, and anyone who has viewed them from Mother Earth and also looked down on them from above, not only has admired their beauty but has marveled at their boiling. Well—presumably they are the fathers of all thunderstorms.

A strong upward current of air is the most noticeable of all things in a thunderstorm. This upward stream of air passing through the cumulous clouds causes them to boil, splits up the drops of water, and carries the smaller drops, with their negative charges, upward and leaves the heavier positively-charged drops far behind. Gravity acts more strongly on the larger drops. Some fall. Now there is a negative charge at the top of the cloud and a positive charge below. Thus a potential is built up, a discharge occurs, there is a flash of lightning and a peal of thunder.

Our attention has been called to a notice of Dr. G. E. Simpson's Kelvin Lecture delivered in London last April. This gives a better understanding of the mechanism of lightning discharges within clouds, between clouds and between clouds and earth. This lecture should be read by all who desire to know more of this phenomenon.

A great deal of wonderful work in the study of lightning has been done in the famous Pittsfield Laboratory of the General Electric Company. When we learn that thunderstorms may induce voltages in the order of 100,000,000 volts, and that voltages of this magnitude may exist between cloud and cloud and between clouds and earth and that the current may exceed 100,000 amperes and that this energy is dissipated in a few millionths of one second, we marvel at the success man has attained in protecting his transmission lines, electric apparatus, and buildings from so Titanic a natural force.

The new material, Thyrite, dealt with at some length in this issue, appears to have the extraordinary property of acting as a valve and letting all potentials above a predetermined limit pass harmlessly to ground, while permitting the working voltage of the line and the current to pursue their course uninterrupted. A material with these remarkable properties was secured only after long and arduous research and its production requires the finest control of temperature pressure, etc. The kind of materialism that leads to such achievements is the kind that is helping the world on its forward march.

J. R. H.

Melioration by Matter

By DR. W. R. WHITNEY
Vice President and Director of Research, General Electric Company

Dr. Whitney delivered the Founders' Day Address at Lehigh University on October 2, 1929, on which occasion he received the degree of Doctor of Laws. We publish this address thinking it will be of interest to our readers.
—EDITOR

AN ADDRESS of this kind, that is, a sortie by a speaker from his rut of ordinary activities, may be controlled by one of two different motives. He may want merely to acquiesce to the wishes of whoever instigated the matter, in a manner to satisfy the logical requirements of the occasion, or he may hail the event as an opportunity to expound a pet doctrine, and, as he imagines, put the world ahead a few notches without its feeling any uncomfortable jolts. The opportunity to construct this paper was welcomed as one of those occasions, which every man should enjoy, of testifying as to the effect of his opportunities and his environment upon him. Everyone has some sort of philosophy, but most of us begin taking inventory only when called upon to explain ourselves in public.

This is a wonderful world, the best ever tested. While being rapidly reduced in all dimensions, it is expanding continually in every particular. It has room for all sorts of people and has unlimited encouragement for countless activities and points of view. As though this were not enough, it has from the beginning encouraged and produced continuous change and improvement. Most fixity and limitations, if they appear, exist only in our crude ideas. Even if individuals become polarized, the things all about them may be made to change by any single unpolarized person. We think we are at a peak of civilization, of intelligence, of power, but the same thought has always persisted, and judging from the past, the future will ever present new interest and improvement.

I like to think of man, advanced though he may be, as really only halfway from nowhere to somewhere worth while. This may usefully fit into whatever philosophy one adopts. It gives us the feeling that if we are not at the peak of civilization, as some fear we are, we may still direct our paths towards new peaks by searching out new ways.

I have felt it worth while thus to outline a broad picture so that I may then take one particular point of view, without fearing lest you imagine that my ideas are rockbound. I want to speak of a kind of changing materialism, useful but not merely utilitarian. I do so because this is a university and you are already more or less oriented, and improving along lines narrowly definable. New physical laws and materials will be your stock in trade, change and improvement your friends and allies. I have just returned from visiting the Indians of our western pueblos, where change and improvement are taboo. These first Americans are not oriented as you are. Even though many of them own Fords and Victrolas, the hard hand of ancient custom weighs very heavily upon them and they have not grown nor changed appreciably in 300 years. Because of dangers which entirely disappeared a century ago, they still build their little stone and mud houses on high mesas. Like goats, they nightly climb up the steep rocks after long days of the crudest kind of corn cultivation under a broiling sun. They are sure that the necessary rains will come if they deliver to a suitable number of snakes the tokens and prayers, songs and dances which they have used for centuries. The snakes take the prayers down into the mother earth and rains are sent up. Every detail of the rites which I saw this year exactly duplicated what I saw there 19 years ago. The same government schools are there, too, but the old immunity to new things is still more persistent. You, on the other hand, if suspicious of materialism, will have continuous new knowledge and may refute the humanistic conception that personality is merely "a fortuitous by-product of a careless universe," for you may really construct your own soul.

Not being a poet nor an artist, I should more narrowly define our common path as material advancement through experiment with things, but I include our brains in things. Let me say at once that I have a letter from one of our leading biologists which assures me that the processes of making our own brains are becoming relatively simple. This should interest us. It has been said that no man is worth over $2 per day from his ears down. The other animals are mostly worth less than this from the ears up; so there must be in the higher animals some cerebral structure of considerable value. This valuable center is the cortex, or what we used to call the grey matter. It is no longer just grey matter, but growing networks of power lines visible under the microscope.

Brains were not apparent in the earlier and simpler forms of life. Later forms became more complex by trying to adapt themselves to new conditions, thus developing a center for reflex action (one might say a center for kicking), and this was a brain foundation. It was not at all a center of reflection. That came much later, and is evidently even yet only imperfectly developed in the best of men. From the zero hour up to and including today, one general rule has governed all life. The lowest plant cell, planted to absorb food from contact with the immediate environment, bred its kind and perpetuated its lineal descendants everywhere earth, light, air, and water were present. But even in these lowly forms there were some which tried to change, and it must have been a great day in protozoa when a cell experimented and discovered that it might change a little, move, and so live better. Of course there were many which would not move, and others which died learning new stunts, exactly as martyrs, heroes, and aeronauts do today. The principles involved, however, apparently brought about all the forms of life we know. Every living thing was entirely satisfied and bred its kind, or else it was not entirely satisfied and it experimented. By experiment it changed and also perpetuated the new idea, or it died in the attempt. At every stage, from amoeba through oysters to turtles, cattle and man, the same simple ideas always held true. This is a great principle, not only because it produces newer and better devices, but because it promises better men.

I do not believe that clams foresaw such pleasure as conversation, for example. This was unexpectedly discovered because animals developed feet, went ashore and experienced new things. It came about as the new things still do, not because word-invention was a necessity, but all words became worth while after experimenting with them. No one felt the need of seeing his bones before x-rays were discovered. Radio was in use for years before a few young experimenters tried broadcasting for fun. Many of our material advances have come through remote experimenters whose marked trait was inquisitiveness. Something was found which no one sought, often not even the discoverer himself. A human urge made him taste, or test it. It tested, or tasted, good. Later we call such meliorating things necessities. But this unsatisfied function is not limited. Its laws are just being discovered. Here philosophers disagree; so some must be wrong. Some decry all novelty, all machinery, and would revert to the beauty of unchanged Nature, as though there were something inherently more beautiful in the Indian, worn and bent by his crude agriculture, than might be produced by continued evolution and education of men.

I do not believe that idleness is the ultimate goal, but the eternal possibility of leisure for new experiment may be. I believe that what we call crass materialism, our new medicines, discoveries, devices, and amusements, may be means to an end, but that end is for the present, at least, the uppermost end of our spinal column, *viz.*, our cortex.

That the physical brain structure houses our character has long been accepted. Now man must learn by experiment how spiritual qualities are determined by material structure, physical forces, and chemical composition.

For several thousand years pioneers have earnestly sought to elevate the spirit. This effort will never cease. They gradually learn the inner nature of matter. Now they see tangibility in materialistic sense, always more remote. At each step matter is interpreted as new forces, so that attributing to matter inherent but unknown power is not new. It may be new to assume that the qualities of character (or personality) are really only evidences or tokens of certain cortex structure. If this is true, the future will be even more interesting than the past or present. In any case, it is probably worth while to keep an eye on our cortex.

Now for a more personal touch.

For the past 17 years I have carefully observed the wood turtles on our 50-acre farm. I found three in 1912, dated them, and set them free. Each year I have found others. Now there are 132 recorded in my books. Many of these carry six or eight of the years between 1912 and 1930, and have been as often weighed and measured. Not over half of them are seen in any one year, but I have learned that they can be depended on and I enjoy studying their habits. I like to say that turtles lie half way from the earliest cell which grew in the ocean to the most recent philosopher ashore, just as mud turtles lie between water and land turtles. In studying the simpler, we have a way to learn about the more complex.

A few years ago I was a guest on board the flagship of our Atlantic fleet. At the officers' mess, the Admiral carelessly started me talking my turtle hobby. I told him there were at least three kinds of turtles: water, mud, and land. Nature had perpetuated these varieties to remind us of the history of growth, and so we find among turtles, first the self-satisfied, exclusively submarine type, then the compromise, the half-land and water, or mud, and finally, the wholly land, or tortoise type. I had been reading about their brains. I reviewed the literature, which shows that the water turtle, if placed upon a shelf at high elevation, will immediately jump off and commit suicide. Fearful of everything new, and ignorantly assuming that water is always at hand, he jumps from a fancied log into the imaginary water and gets a real surprise. Water turtles are so inexperienced and stupid that even when blindfolded they do not hesitate, but jump at once. They show quick reflex action, but no reflection. The superior land turtle, on the other hand, has been ashore. He has had experiences which he remembers. Put on the same shelf, he will cautiously creep to the edge, look carefully about, and only jump when it seems safe. If blindfolded he prefers to sit still and work the bandage off before taking any chances.

Now the interesting thing is that it is only among these land turtles that cortex, or grey matter, begins to show in animal brain. Water turtles are deficient in it.

The cortex interests me because it seems to be the forerunner of all power, telegraph, and telephone networks. It contains countless fine electrical conductors, or nerves, threading to and from every part of the body and joining in myriads of possible new hookups in the grey matter. It looks as though every new experience of the mind or body was responsible for added conductors in the brain. It gives one the impression that mind may be sometime analyzed and that our reasoning processes may resemble the actions of a telephone exchange.

Most animals below the turtle fail to exhibit cortex, and among the turtles it is only the land type which first distinctly shows this valuable mental structure. In other words, in some way experiments and experience cause a growth at the one end of the spinal column, which growth becomes not merely a switchboard for muscle, but rather a remembering, thinking, reflecting, and inventing electrical apparatus. The rules of its production seem to be based on seeking new experience, which, in case of the turtle, evidently came very rapidly when he went ashore.

This was probably getting pretty tiresome for a dinner party. At any rate, at this point, the kindly old Admiral, whom I had nearly forgotten, patted my knee and said, "Whitney, I see now what you are driving at. You are right. I don't go ashore much myself."

The large majority of any living type remain true to the past. A few only, by developing novel structures direct their activities into new fields. Today there are being studied as never before, the material and mechanical processes which determine advance in countless fields. A new concept once installed in some brain, works upon the same old world matter in new ways and makes entirely new tools, perhaps superior to the cruder arms and fingers which formerly developed as their advantages were discovered. It often seems that the mere act of novelty develops into a material service. This has always occurred in spite of the opposition which newness usually encounters. The turtle which first left the safety of the water and crept ashore is in this respect not unlike the aeronaut, who is certainly subject to more new experiences in his novel medium than is the crowd on solid ground. The same old evolutionary force drives them both. This is always due to new electrical contacts or different hookups of circuits in cortex capable of countless new interconnections. Is it not possible that when the mechanics of such interesting operations are better understood the advantage of high class, materialistic education will be more evident?

As my object is to help you by any knowledge which I can briefly transmit, I probably ought to tell you something about industrial research work. I have already tried to give the impression that the ordinary material *results* are not worth talking about here. Their influence on the spiritual man is.

Our mechanical age is a great help to the spirit of man. It is not so much that he is enabled to live easier, to control his surroundings and extend his individual selfish interests, but he is actually enabled to be a better neighbor in the true sense. He will work and be worked. He is learning how to coöperate better, how to intercommunicate. He is now depending more than ever on contributions of others for his own happiness, but he is also enabled, in thousands of highly specialized fields, to contribute to the general welfare. The mediums of exchange are forever increasing.

To stifle continuous appreciation of the infinite possibilities of matter is contrary to the rule by which life has developed from the beginning. To take a narrow view is to hinder that further spiritual development which can only be brought about through more new knowledge. The modern philosopher who believes that spirit is a property of matter, that the soul of a faithful dog is bred in the bone, learns from his experiments to seek a mechanistic scheme broad enough to cover human nature, including the most significant spiritual life. He will probably make better use of new physical facts than he who neglects new truth.

In pure materialism we need those men who specialize in new and narrow fields of experiment, and we need those who can weave together for better use the new knowledge. More than all, we need men who appreciate the growing whole so that all of us may be improved and elevated.

It makes the way appear easier to look at all human advance as dependent on improved cortical structures the laws of whose production will become clearer through research. It is just like the growing grey matter in turtles. The material constructions of new cortex are coextensive with the spiritual expansion.

It is within my lifetime and that of this University that the entire development of electricity has occurred. For a time it was confined to a few lamps and the production of the current generators for lighting them. Hundreds of university professors had contributed basic principles resulting from their physical researches. Except for the researches of Mr. Edison, the golden jubilee of which is being celebrated this year, very little organized research work was being done even in lighting forty years ago. In my little field at Schenectady, at the end of one year's work, two or three men constituted our research staff, and even after several years a dozen men covered the pure research work. We certainly would have given up in despair if on some Monday morning of those early days, our present staff of nearly 500 had suddenly appeared. What could so many men actually undertake? Could there be any corresponding deficiency in the subject of electricity? But change and growth controlled even our little jobs. And now the main problem of a laboratory is finding enough men competent to do experimental work, and then space and equipment for them. It is pretty clear today that no matter what electricity actually is, it seems to be the ultimate essence of which everything is made and by which most processes take place. New services will be proportional to the investigations made and more complex cortex will develop from every experience. This becomes more apparent as numbers of operators increase, for in this way the irregularities due to special cases are less prominent. One man may be interested in some electron reaction apparently quite remote from a utility; another, acquainted with the data, fits them into his work and so discloses a new rectifier, a new lamp, a new radio tube, a new alloy, or a new insulator. Others use such things for displacing human labor, doing new work, or increasing human contacts. Every laboratory has the same experience. During our first year we worked on little except lamps and lightning arresters. Today there are hundreds of subjects, and scores are added yearly. They are neighborly, and reinforce and support one another, just like, and probably because of, new connections in brain cortex.

Up this valley a mile or two, and up and down all valleys and all hills, and even inside some of them, are men who have no such opportunities as we have. They are mainly attachments to the farm tools, the coal drills, or the mills they operate. If you cannot supply them a cheaper phonograph, can you furnish something different? It might turn out even better. University men like Kelvin, Raleigh, Ramsay, and Crookes have already pictured the use of coal at the mines to generate electricity which can then be broadcast. Everywhere it goes, power can displace human physical effort—heat and cool homes, transport and entertain peoples, etc. All this is old, but so is the difficulty of doing it. The difficulty may even be dying at the moment. The leaders mentioned are dead. Young men not already preoccupied must assemble anew the growing knowledge. They must show that conditions calling for many small steam units at the remote ends of expensive coal shipping lanes should be obsolete. Everything changes. Perhaps a combination of powdered coal burners, some new river flood control plan, the modern interstate electric power networks, or some new electron devices for local power distribution will serve further to liberate labor for riding in automobiles and listening to jazz until other changes show the next and better step. The mind which first outlines a successful solution to this obviously desirable undertaking will not necessarily be the one who feels the need most strongly. He will be one who has already built into the structure of his brain enough of the related matter, and some that was formerly not so related, to have formed a new or partly new combination. A stock of the old cortex, augmented by a few new mental conductors, becomes the materialist's picture of the production of new service.

My cortex is probably electrically lopsided, and so I will leave electricity to say, for example, that biology is being advanced by leaps and bounds by research men in good universities, that biochemistry and organic colloid chemistry are rapidly growing sciences, that cytology, neurology, heredity, and genetics are an interlocking quartette, locally more important than rotation of crops. The local agricultural possibilities are pretty well known and discounted, but mental and spiritual development is evidently only starting. Exuberance of spirit shows itself well in sports, college athletics and aeronautics, for example, but there is greater sport in uncovering some fact of nature which has been concealed from the beginning of time and which may soon become an important exchange token. This fact will be better seen and appreciated as colleges continue to help and encourage teachers to be also doers.

It is too early to claim that interlocking sciences will develop the superior psychological human as they develop more mundane materials, but modern studies of cortical structure indicate it. Bertrand Russell has just written: "While we alter the environment to suit ourselves, we do not much alter ourselves to suit each other. The reason is, of course, that the sciences that deal with the formation of human character are far less developed than those that deal with the inanimate world. This, however, is rapidly changing." It is this changing and growth that the world-pessimist, like the complacent clam, overlooks, but which an unsatisfied turtle appreciated.

All early improvements of living things were perhaps entirely forced by changes of environment. Possibly land turtles arrived when water evaporated. Similarly, early changes in man came through struggles to keep alive. Perhaps he just had to make arrows to get food. At every stage, being satisfied perpetuated animal kinds, while trouble, dissatisfaction and danger engendered improvement. So with man, assurance of food and warmth was always enough to stop the climbing of some, but never of all. This peculiar process has been long studied by psychologists. Petroff, after a quarter century of well-directed research on dogs, concludes that "the chief condition for attaining a goal is the existence of obstacles." Think of the added load the turtle had to carry when he came out of the water and first climbed the bank—the weight of his volume of water. The self-satisfied prefer to have their obstacles removed, but apparently the overcoming of them is the elevating process. The boy in the wealthy family can afford more obstacles than the poor boy and so has a greater opportunity to advance.

But a further lesson lies here. Seeing the value of obstacles, we may search them out. We need not call them obstacles; they may be merely the processes of research.

While perhaps necessary once, men need no longer wait for external forces like hunger to develop them. We learned by experience that while the material world is filled with unseen riches, they must be sought to be discovered. The lesson first learned for bare necessities also applied to our material luxuries. It certainly applies to the luxuries still undiscovered, and must be applied with increasing ardor to the spiritual improvement of all mankind.

Simulating Sunlight

By M. LUCKIESH
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IN the great drama of electric lighting which has been enacted for a half century the two prominent roles have been played by the arc and the filament-lamp. As scientific curiosities these were born at about the same time—over a century ago. As practical devices they appeared almost simultaneously—about a half century ago. Then began a great struggle between them for supremacy in the many fields of artificial lighting as a necessary partner of vision. For years the battle raged. Temporary victory for one source was often turned into temporary defeat. The tide of fortune ebbed and flowed.

After a quarter of a century the arc seemed to be doomed. Notwithstanding its admirable resistance it steadily lost territory. It clung doggedly to street lighting, to large interiors, and to certain special fields. Improvements in the filament lamps continued to press the arc on all fronts. It was forced from the streets, but it still clung to photography and certain small fields. Finally, at the present time, the arc in lighting applications is chiefly represented by the carbon arcs in large searchlights, by the mercury arc in a small part of the industrial field, and by special arcs in specialized fields.

The fifty-year battle was won by the filament lamp because behind it were greater safety, simplicity, flexibility, and divisibility. Today as one views the thousand types of standard and special filament lamps, ranging from a fraction of a watt to 50,000 watts, the great advantages of these fundamental characteristics stand out clearly. Efficiency of light production is very important—but not all-important. Simplicity can overcome a large handicap in efficiency. And so it is with flexibility and the other factors.

But just as the filament-lamp surveyed its vast territories with justifiable pride and the arc was becoming reconciled to its very meager fields, ultraviolet radiation stepped from a very minor rôle in the drama to an important and popular one. For many centuries sunlight has been more or less vaguely recognized as being directly beneficial to human beings. Perhaps even primitive beings instinctively recognized its beneficence quite beyond its warmth and its essentiality to plant life—the foundation of all food for mankind. Less than a score of years ago the first vitamin was discovered. Scientists trained their intellects and methods upon radiant energy as a vital factor in life and health. Some fundamental facts of great importance have been unearthed. Among these is the fact that certain radiations near the short-wave limit of the solar spectrum are very effective in connection with certain diseases, certain vitamins, and certain other factors bearing upon health.

Notwithstanding the great progress of scientific research in these directions, the field as a whole is still in the twilight zone of knowledge. It is such a dim dawn that the imagination flourishes. A great demand was created for ultraviolet radiation. The filaments of modern tungsten lamps radiate it in much less quantity than the arcs. The latter came to life. Professional therapists have been using them rather widely for several years. Scores of outfits are available to the householder and wherever health is given some consideration the sale and use have long ago overflowed the boundaries of actual knowledge. There is no doubt in regard to certain benefits to life and health but much research is necessary before the entire matter emerges from the present twilight stage.

Ignoring the unfounded claims, there are enough knowledge and experience available to place a certain degree of confidence in the health-value of sunlight. Besides the data available we are confronted with the fact that solar radiation has been one of the powerful environmental factors since life began on earth. Air, water, soil, and solar radiation are the primordial sources of living things. Whether we shall be disappointed when scientific research presents a reasonably complete picture depends upon how far our hopes have carried us. However, it is very likely that ultraviolet radiation of certain wavelengths will play a prominent rôle in a new era of lighting, for health as well as vision, which is now upon the horizon.

Naturally, this greatly extended interest in ultraviolet radiation gave rise to renewed interest in the arcs as producers of it. However, for the most part the old arcs were brought out, dusted off, slicked up a little and sent forth to help human beings who had become less and less exposed to sunlight as they extended and complicated their artificial world more and more. Some new work was done along the line of impregnating carbons with chemical elements and compounds which would make them emit more of the desired radiation. Quartz mercury arcs were made more convenient, but these existing sources were not fundamentally altered. The new demand for "health-giving" rays might bring such sources back into lighting in special cases. However, if lighting is to be broadened to include health as well as vision, the same characteristics which won the struggle for filament lamps are still important. For a number of years research has been directed toward the development of a new source which could broaden or extend the scope of lighting.

A new light-source is a rare event even in this rapidly moving age of scientific development. The last great improvement of wide application was the gas-filled tungsten lamp developed by Dr. Langmuir and his colleagues fifteen years ago. Recently an interesting newcomer has arrived which appears to have great potentiality. After years of research and development the engineers of the General Electric Company and its foreign affiliations have achieved a combination of a filament and an arc in the same bulb. Inasmuch as simplicity is such a valuable characteristic, this development is indeed noteworthy. Arcs and their accompanying mechanisms are relatively complex. In this Type S-1 Sunlamp the filament and a mercury arc (in pure argon) operate together as if they had never been engaged in a struggle for supremacy in the lighting field. It is a symbol of hope to the idealist.

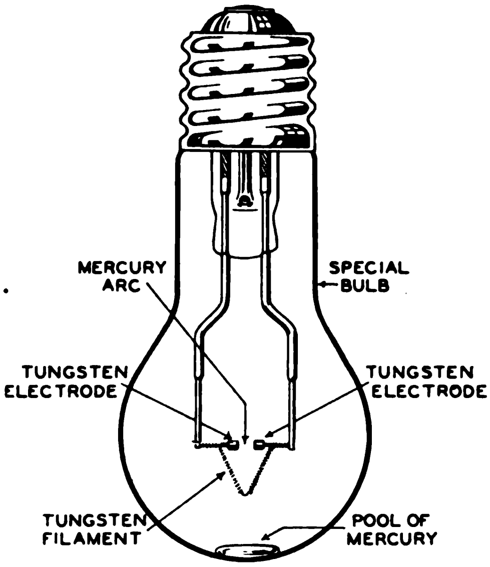

Fig. 1. Diagrammatic Sketch of the Lamp Bulb of the G-E Sunlamp

The new lamp consists of a V-shaped filament hanging downward with its tip near a small pool of mercury in the bottom of the bulb. Above this filament and in parallel with it is a pair of tungsten electrodes. The bulb contains pure argon. No tilting is necessary to start the lamp. Practically as soon as the filament is lighted the arc strikes. The lamp can be operated throughout a wide range of angles.

The Type S-1 lamp is essentially a low-voltage source and the volt-ampere characteristic of the transformer is important. At present the lamp is approximately 400 watts. The no-load volts of the secondary are approximately 35. When the switch is closed the filament takes about nine amperes and the drop across it is approximately 33 volts. Almost instantly the arc begins to operate without any further action on the part of the user. Now the mercury arc between the tungsten electrodes is operating in parallel with the tungsten filament. The volts drop to 11 and the total current passing through the filament and the arc is approximately 30 amp.

The relative amounts of light (as measured visually with a photometer) from the arc, electrodes, and filament are to some extent under the control of the lamp-designer and can be varied somewhat as experience dictates. At the present time the arc supplies about one-fourth of the total light emitted by the lamp. Most of the light—about two-thirds—is emitted by the tungsten electrodes.

The color of the light is nearer white than that emitted by melting tungsten. In other words, the color-temperature of the light from the combined sources is above 3500 deg. K.

Inasmuch as the solar spectrum ends at a wavelength designated as 2900 Å, it is ideal to limit the spectrum of an artificial source of radiation at about this point. However, moderate quantities of radiant energy as short as λ2800 and even somewhat shorter do not seem to injure the outer membrane of the eye. It is also known that radiant energy between λ2800 and λ3100 is relatively more active than other radiations in producing certain desirable physiological results. Therefore, if a source is to have a wide usage in lighting for health as well as for vision the spectrum of its radiation should practically end in the neighborhood of λ2800.

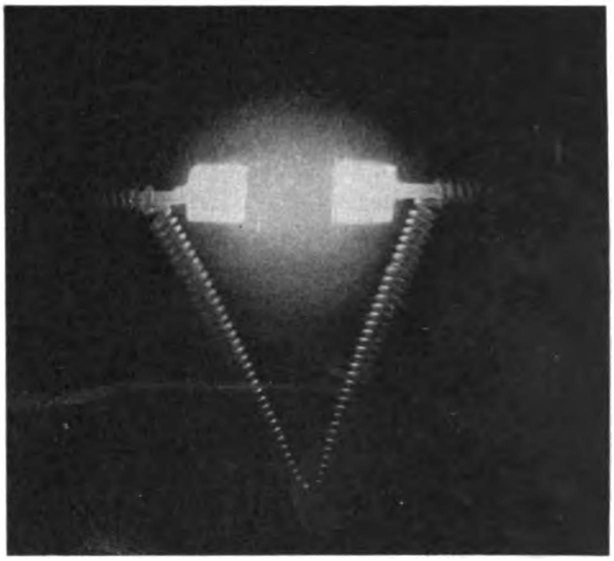

Fig. 2. Close-up Photograph of the Filament and Electrodes of the Lamp When in Operation

With this new Type S-1 lamp this is accomplished by means of a special glass bulb. A wide variety of glasses can be produced for this purpose. Aside from certain fundamental ingredients, iron, as an impurity, is exceedingly annoying. It must be reduced to a very low minimum in order for the glass to transmit efficiently the radiation from λ2800 to λ3100.

In entering this broader field of lighting, reflecting and transmitting materials assume a new importance. During recent years when little thought was being given to conserving and controlling ultraviolet radiation, poor materials have often been used. For example, vitrified porcelian reflectors such as are common in lighting practice have been sold with certain equipments for producing ultraviolet radiation. As a matter of fact, such enamels absorb practically all the valuable ultraviolet energy. White pigments differ greatly as reflectors of ultraviolet. Zinc oxide absorbs practically all the ultraviolet radiation, but some white pigments are fairly satisfactory. Even the vehicle in paints and lacquers must be taken into consideration. Among the common metals aluminum and chromium are satisfactory and a properly oxidized aluminum surface is particularly efficient in reflecting ultraviolet radiation of primary interest.

This new source equipped with a bulb which absorbs practically all the radiation shorter than λ2800 appears to be safe for the eyes without the use of goggles, just as solar radiation is. However, we exercise caution in using sunlight over large areas of the body and we avoid looking at the sun. These same precautions should be exercised in using any source of ultraviolet radiation even though it is equipped with a glass which absorbs the radiation of shorter wavelengths such as are transmitted by quartz.

This Type S-1 tungsten-mercury lamp, when used in a proper reflector, produces the same degree of erythema (reddening of the skin) in the same or even less time at 30 in. from the source as is produced by midday midsummer sunlight. An average of many tests indicates that, as measured in foot-candles, it is at least 20 times more effective than good summer sunlight. The susceptibility of the skin of an individual varies widely over various portions of the body. Furthermore, the susceptibility of the skin of individuals varies considerably. However, for the most part the variation is about one to three in relative terms. The character of the tan produced by successive reddenings of the skin by means of natural sunlight or this new artificial sunlight is the same. A good tan seems to be a protection against reasonably excessive exposures to ultraviolet radiation from these two sources without eliminating the effectiveness of the so-called health-rays.

Much scientific research is needed in this entire field of radiation as a health influence before we shall know how much benefit can be expected from ultraviolet radiation applied at low intensities which do not produce appreciable erythema. Researches have been conducted chiefly with high intensities from sources rich in ultraviolet radiation. Already we have obtained apparently beneficial results even from ordinary tungsten filaments enclosed in special bulbs. In fact, researches may establish the fact that such lamps supply sufficient ultraviolet radiation, when applied for hours as in artificial lighting, to be beneficial to health while supplying the needs of vision. It must be determined whether or not exposure of the hands and face is sufficient to obtain the benefits. If not, perhaps this era, which seems to be approaching, may emancipate males from the present slavery to habit as the fairer sex emancipated itself. The necks and arms of men may be generally bared and of course sheer stockings and short trousers *could* be adopted. This is a rapidly moving age and even men who so habitually criticize the fair slaves to style may possibly shed their coats and collars and sleeves and whatnot.

But to return to the new light-source, which indeed is epochal; it may not only open a new era of lighting, it is also likely to lead to a development of other new light-sources. Notwithstanding the marvelous progress of lighting during the past half century, epochal developments of light-sources have been very few. It is befitting that in the year of *Light's Golden Jubilee*—a tribute to Edison—this truce between the arc and the filament was achieved. Now they are wedded and housed in the same bulb—a simple combination, now that it has been achieved. But simplicity is a great virtue, to which the arcs of old have testified and which the filament-lamps have glorified.

Small Starter for Throwing Motors Across the Line

A new manual starting switch has been designed particularly to meet the demand for a small device which will throw motors across the line. The switch has a maximum rating of one horsepower, 110 volts, and two horsepower, 220 to 600 volts, 3-phase.

The device consists of a tumbler switch and two small thermal cutouts mounted on a common textolite base. By means of suitable interlocks, the switch can be locked in either the open or closed position.

Of particular value, in the textile industry, for example, is the optional use of either single or double pedestals on which the switches can be mounted in positions near the controlled machines.

In designing the switch, special attention was paid to the cutouts to make them particularly reliable. The links are made of tinned copper to prevent oxidation, and the contact spring and post are also tin-plated for the same reason.

Thyrite: a New Material for Lightning Arresters

The Ideal Arrester—Thyrite—Its Properties—Its Operating Characteristics

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Lightning Arrester Engineering Department, Pittsfield Works
General Electric Company

(A paper read before A.I.E.E. Mid-winter Convention, New York City, January 27-31, 1930)

A LIGHTNING arrester to be successful today must be able to protect apparatus from the harmful effects of lightning and must prevent or suppress the flow of system-follow-current after the discharge has passed through the arrester. After functioning, the arrester should be in condition immediately to repeat its operation without alteration of these two essential properties.

The Ideal Arrester

It is usually of value to set up an ideal in order that one's approach may be orderly and consistent. The ideal arrester may be defined as one which passes zero current as the applied potential is increased until the critical discharge voltage, set by the designer, is reached, when current begins to flow in whatever amount is needed to hold the potential across the arrester constant at the initial discharge value. The current ceases when the applied potential drops below the critical value for the arrester. The critical voltage for such an arrester should be unaffected by the rate of voltage application; in other words, it should have no time lag. The volt-ampere characteristic of such an arrester is shown by Chart *A* in Fig. 1. Chart *B* shows voltage waves of various steepness, held down to the same critical voltage at the arrester. With such an arrester the effects of wave front, the duration of the wave (lightning), and the maximum current are removed from the discussion.

Since we are striving to approach the ideal it is worth while to consider the meaning of these ideal characteristics. If the potential remains constant for any effect, then the resistance varies from infinite resistance at zero current to zero resistance at infinite current. Thus the RI curve is an equilateral hyperbola and its equation is $RI = C$, where C is numerically equal to the critical voltage. This curve is shown by Chart *C* in Fig. 1.

If log R is plotted against log I, as at D in Fig. 1, then the curve is a straight line having a slope of 45 deg. This slope is important, for in the general equation which is $RI^a = C$, the exponent a is the slope of the RI curve when plotted on log-log paper. Thus for the ideal case, the slope is unity (tan 45 deg. = 1) and the equation is $RI^1 = C$. When $I = 1$ amp. then $R = C$, no matter what the exponent may be. Thus when a and C are known the characteristic is immediately known, for C determines the position of the curve and a determines its slope.

Lightning Arrester Material—Thyrite

In the search for a suitable arrester material the first requisite is that it shall have a slope similar to that shown by Chart *D* in Fig. 1, although it may not be possible to reach the ideal and get a slope of one. If possible, the characteristic should not be affected by the rate of voltage application nor the rate of current rise through the material. Its characteristic should not be affected by whether the current is increasing or decreasing. Other desirable characteristics are: reproducibility, permanence, ability to return to its original characteristics if overheated, and other properties of a similar nature.

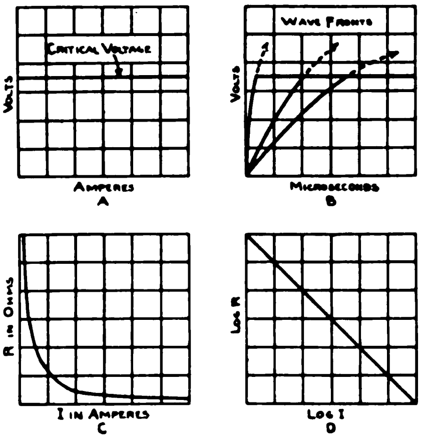

Fig. 1. Ideal Lightning Arrester Characteristics

A search for such a material having the properties described was begun in 1923 and this paper is the first public announcement of the results of this work. A material has been developed having mechanical properties somewhat similar to those of dry-process porcelain, but possessing the remarkable property of being substantially an insulator at one potential and a good conductor at certain higher potentials. This material, for which the General Electric Company has adopted the name Thyrite,* represents a new class of conductor which covers the middle ground between the insulator and the conductor.

No attempt will be made here to describe the manufacture of Thyrite, except to state that its successful production involves the very accurate control of a large number of variables. This has been accomplished so that now it appears that Thyrite can be manufactured within sufficiently close limits for successful operation. At the present time Thyrite for arrester use is manufactured in the form of disks, six inches in diameter by three-quarters of an inch thick and also three inches in diameter by one inch thick. It probably can be made, however, in any form which can be molded.

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*Thyrite—meaning gate or opening.

In Fig. 2 are plotted the *E-I* and *R-I* characteristics for a six-inch Thyrite disk for which $a = 0.72$ and $C = 580$ respectively. When considering the application of Thyrite it should be noted that the constant varies directly as the thickness of the piece but not inversely with the area as does the ordinary resistance. For instance, with an exponent of one, the constant for the piece depends on the length but is independent of the area. To make this clear, we may consider the effect of doubling the area, remembering that the constant is defined as the resistance at one ampere, which, with an exponent of one, is inversely proportional to the current. By doubling the area, the current in the original area is reduced to one-half, but the resistance of each half is thereby doubled and so the total resistance remains unchanged. It should be noted that these relationships are dependent upon the definition of the "constant" as the resistance at one ampere. As the exponent approaches zero as a limit these relationships approach those of the ordinary resistor.

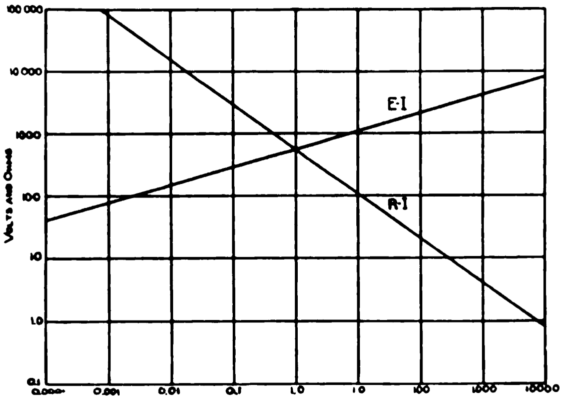

Fig. 2. Characteristic *E-I* and *R-I* Curves for a Thyrite Disk 6 in. Diameter and ¾ in. Thick

It is interesting to note the wide range over which the change of resistance with current takes place, the available data showing that the law holds over current ratios of 10,000,000 to one. Each time the voltage is doubled the current increases 12.6 times for Thyrite with an exponent of 0.72. Thus, if the potential increases 16 times the current increases 25,000 times.

Time Lag

Up to the present time, the tests made have not disclosed any time lag. One of the best illustrations of this characteristic is shown in Fig. 3, which shows test results taken on ninety disks connected in series. The characteristic of each disk was first determined with direct current using a potentiometer up to 0.1 ampere. The exponent for the entire stack was found to be 0.7 and the constant 500 per disk. The whole stack was next tested with alternating current with sufficient potential so that a crest current of nearly four amperes flowed through the stack. Oscillograms were taken and the instantaneous resistance calculated and the results are plotted in Fig. 3. The stack of disks was then tested with a million-volt impulse generator, the current being determined by the voltage drop across a series water tube. The voltages were determined by sphere-gap measurement. These results are also given in Fig. 3 and fall on the same straight line as the data taken with alternating current and direct current. That the results fall so nicely on the same characteristic with such widely varying wave front shows clearly that no measurable time lag exists. That there should be no time lag seems reasonable, for the material always acts as a resistance, and its operation does not depend on any arcs or sparks or the breakdown of any dielectric.

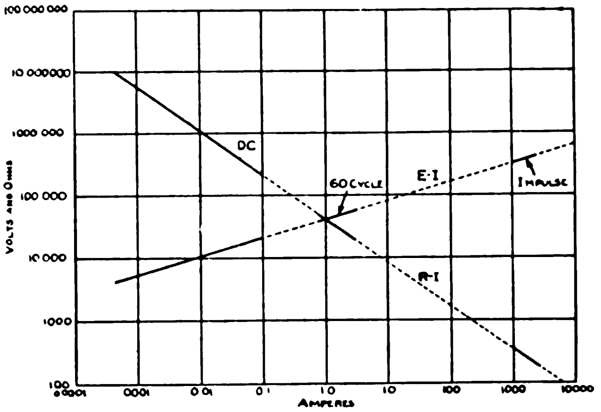

Fig. 3. Tests of Ninety 6 by ¾-in. Thyrite Disks with A-c., D-c., and Impulses

A large number of other data have been taken since those shown in Fig. 3, in which the cathode-ray oscillograph has drawn the volt-ampere curve. These data have always fallen on the same straight line as the characteristics obtained on the same piece with direct current. So today the men working in the laboratory with this material, under transient conditions, trust its characteristic as much as they would the performance of a piece of nichrome wire or other similar resistor.

Operation on Alternating Current

Since the current varies as the $\frac{1}{1-a}$ power of the voltage, with an exponent 0.72, the current will vary as the 3.57 power of the voltage. With a sine wave of applied potential, the current wave will not be a sine wave. An oscillogram showing the wave form of the current is given in Fig. 4. In case the potential wave contains tooth ripples, these will be greatly magnified on the crest of the current wave. It should be noted that the current wave is perfectly symmetrical, illustrating the fidelity of the material whether the current is increasing or decreasing. As will be seen later, this is just as true for an impulse lasting but a few millionths of a second.

Because the current wave is not a sine wave, it is desirable always to speak of both the voltage and current in terms of actual instantaneous values and not effective values. Thus, with the ordinary resistor, one may find the corresponding current from either the effective or the crest voltage; but with Thyrite, if the potential is given in effective volts, it must always be changed to crest volts and the crest current found. If the energy loss in the piece with an applied sine wave voltage is desired, the product of the crest voltage and the crest current is to be multiplied by a factor taken from Fig. 5 for the particular exponent possessed by the piece.

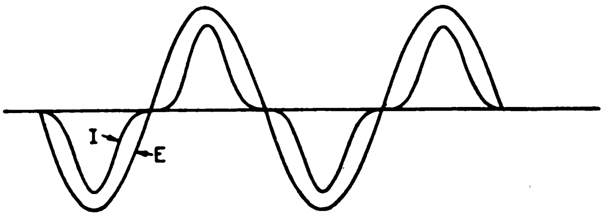

Fig. 4. Oscillogram Showing Wave Form of Current Produced by a Sine Wave Voltage

Effect of Change in Temperature

The effect of increase in temperature is to lower the resistance of the material especially at the weaker current values. The results of a series of tests to determine the effect of temperature are given in Fig. 6. When cold, the original values reappear. These data indicate that for the usual temperature changes in an arrester, under operating conditions, the effect on the resistance will be small.

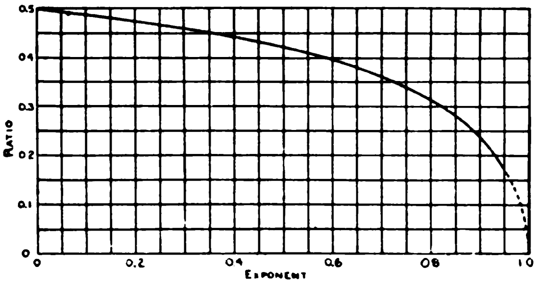

Fig. 5. Ratio of Average Power Expended in Thyrite to the Maximum Instantaneous Power with a Sine Wave of Voltage Applied

Permanence and Life

Several samples of the first Thyrite made have been on life test for more than five years, and tests at frequent intervals have shown the characteristics to be practically unchanged. The samples were connected to an 1100-volt 60-cycle source, the current through the pieces being sufficient to raise their temperature to about five degrees above the room temperature. Other tests have been made in which the sample was exposed to the weather for a year with various degrees of protection and no deterioration has been detected either by inspection or electrical tests. Still other samples have been tested with both impulse and alternating current applied and no changes in the material were noted, even after several hundred impulses were applied.

Summary—Thyrite

It seems then that a material having the proper characteristics for lightning arresters has been found. It has the desirable hyperbolic characteristics, not to a degree indicated in the ideal arrester where the exponent is one, but sufficiently so that it may be used successfully. It has no measurable time lag and is durable. Its characteristics are permanent and not affected by use.

The Arrester

In designing lightning arresters for all voltage ratings, it is worth while to build them in the form of standard units which will all be alike, various numbers being used to correspond to the different ratings. This will greatly simplify manufacturing and stocking the arresters. For certain conditions, it may be necessary to supply smaller or part units, and this applies particularly to the lower voltages. The standard unit is rated at 11.5 kv. for grounded neutral. Thus for a system rated at 115 kv. with a solidly grounded neutral ten units would be used. The arrester as a whole does not employ a series gap, each unit being complete within itself and containing its own gap structure. Fig. 7 shows a single unit and Fig. 8 a group of six in series, such as would be used on a 69 kv. grounded neutral. No steel work is required for the 69 kv. arrester. The units should be mounted on a concrete foundation to keep clear from weeds, snow, etc.

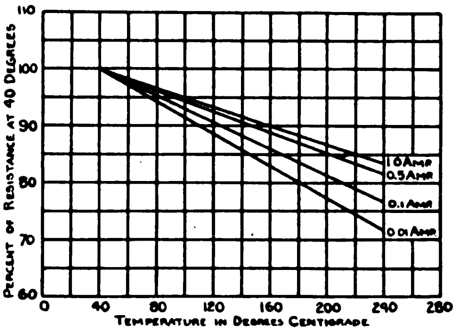

Fig. 6. Effect of Temperature Change on Resistance of Thyrite with Various Currents

Performance Characteristics

For the first time in the history of lightning protection, it becomes possible to calculate accurately arrester performance. The volt-ampere curve for the 11.5 kv. unit is given in Fig. 9 and is the curve for 11 six-inch disks in series, making a total height of 8¼ in. In this design the disks are coated with copper on both sides by the Schoop process and stacked up inside the porcelain container. It is necessary to use a series gap arrangement which is housed in each 11.5-kv. container.

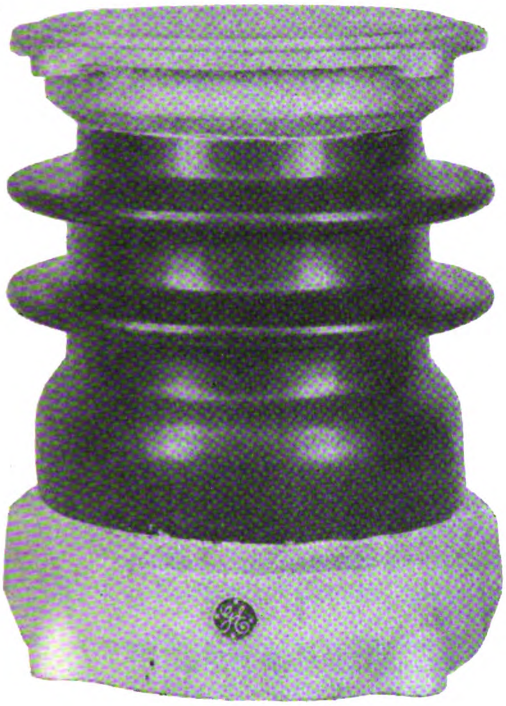

Fig. 7. 11.5-kv. Thyrite Lightning Arrester Unit

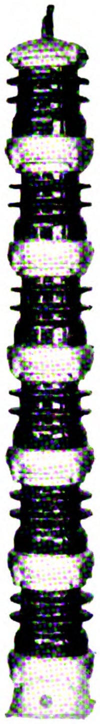

Fig. 8. 69-kv. Thyrite Lightning Arrester

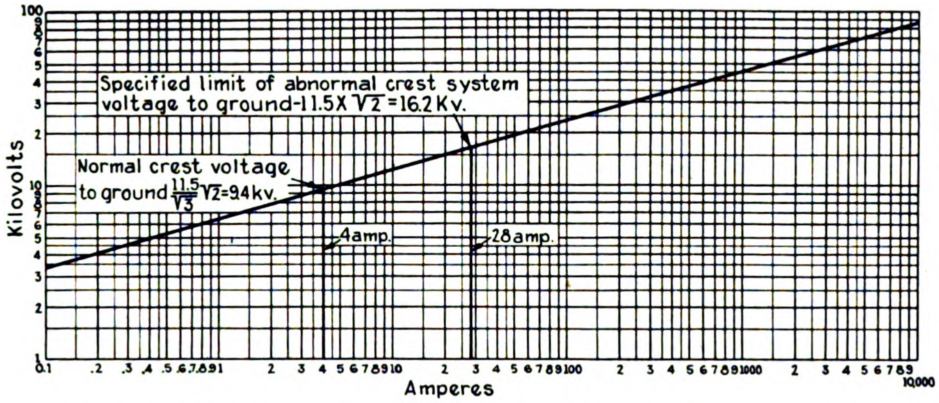

Fig. 9. Characteristic of 11.5-kv. Thyrite Lightning Arrester for Grounded Neutral Circuits

The reason for the series gap will be apparent from an examination of the characteristic curve. The normal voltage to ground is 9.4-kv. crest, which would cause a steady current of four amperes crest to flow through the arrester continuously. If an over-voltage is applied, as may occur in the case of dropping a load and over-speeding generators, a potential as high as 16.2 kv. may be applied between the line and ground. With this potential a current of 28 amp. would flow and thus for safe operation it is necessary that the gap be capable of stopping the flow of current after one-half cycle, even if the impressed potential is 16.2 kv. and the current 28 amp. A single arrester gap is unable to break an arc of this magnitude and it is, therefore, necessary to break the single gap up into a series of small gaps, which possess the property of quenching an arc if the voltage distribution across the gaps is such that the potential per gap is kept small. Because of the necessity of introducing several small gaps in series two opposing conditions develop. With a 60-cycle voltage applied, the distribution of potential between the gaps must be kept uniform, otherwise spitting would occur, which not only would set up radio interference, but would make impossible the operation of the arrester with several units in series, with several gaps in each unit. At the same time unless some means could be found to upset the uniform distribution, under impulse conditions the arrester breakdown would be too high for satisfactory protection. Fortunately this problem has been solved so that a uniform distribution is obtained with the application of system potential, but the distribution becomes non-uniform when a steep wave front of potential is applied. Thus the impulse ratio is kept close to unity, as for example, the breakdown of the series gap at system frequency is about 35 kv. crest, while with the application of an impulse requiring one microsecond to reach breakdown it is about 45 kv. crest. Thus for currents up to 1000 amp. the arrester unit holds the voltage to a value not in excess of 2.8 times its rating.

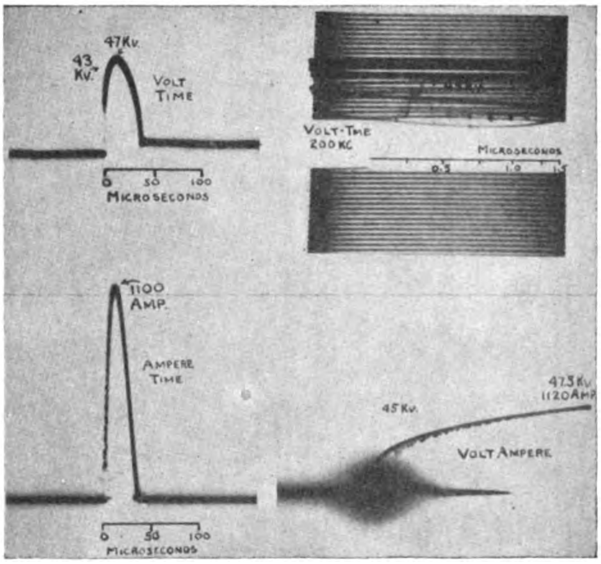

Fig. 10. Protective Characteristics of 11.5-kv. Thyrite Lightning Arrester

From the curve shown in Fig. 9, it may be seen that 45 kv. corresponds to a current of about 1000 amp., so that for discharges involving currents smaller than 1000 amp. the gap breakdown represents the limiting potential, while for currents in excess of 1000 amp. the *IR* drop represents the maximum voltage applied to nearby insulation in parallel with the arrester. Cathode-ray oscillograms taken on a complete 11.5-kv. unit are given in Fig. 10. It should be noted that in this illustration the volt-ampere curve shows no loop, the increasing and decreasing characteristics following the same curve. The close agreement between this volt-ampere curve and the curve in Fig. 9 illustrates how accurately the arrester characteristics can be determined.

When applying arresters to particular circuit conditions it is very desirable to be able to determine the performance characteristics under those conditions. In Fig. 11 are shown the characteristic curves for arresters whose ratings extend from 46 to 230 kv. grounded neutral. Plotted on the same sheet are curves which may be called impulse regulation curves for the transmission line. The arrester is considered for the given case to be at the end of a transmission line whose surge impedance is 500 ohms. For each arrester rating an impulse regulation curve is taken, corresponding to the flashover value of the insulation used on that line. If for 230 kv. 14 insulator disks were used, and for 138 kv. ten disks were used, the flashover voltages corresponding are 1900 kv. and 1410 kv. for a particular impulse wave. The curved lines represent the potential across a resistor at the end of the line which allows the corresponding current to flow to earth. For instance, with zero resistance between the line and ground a complete current reflection will take place, and for the 230-kv. case, the current to ground would be 3800 amp. The value of voltage where the arrester volt-ampere curve crosses the impulse regulation curve for the corresponding number of insulators used represents the maximum voltage allowed by the arrester. Thus for the 230-kv. arrester, the maximum potential is one million volts. For any impulse less than this the arrester potential will be less.

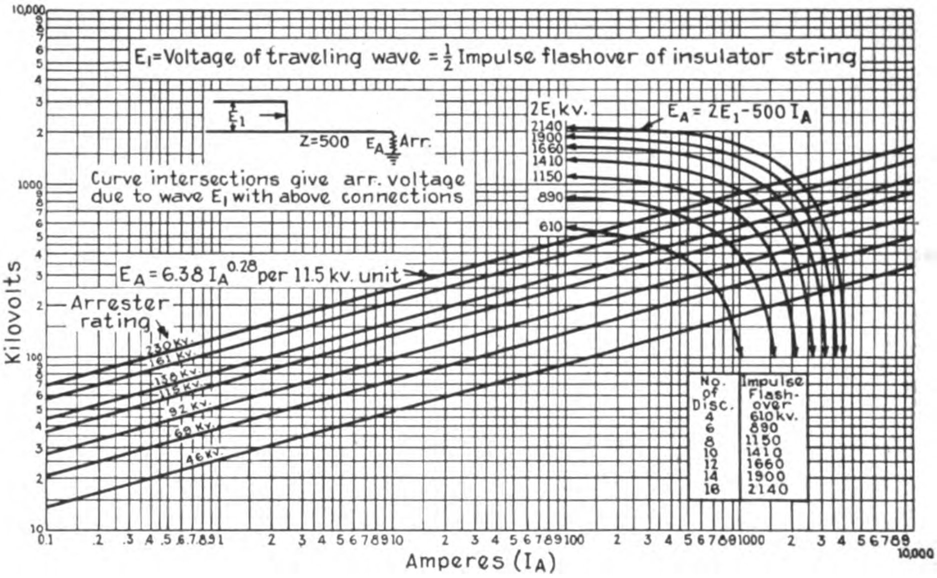

Fig. 11. Grounded Neutral Thyrite Arrester Characteristics with Traveling Waves (Arrester at End of Line)

Fig. 12 is plotted for conditions similar to those represented in Fig. 11, except that the arrester is connected to a bus with two incoming lines so arranged as to deliver simultaneous impulses to the arrester. Such a situation is often found in practice where double-circuit lines are connected to the same bus. Thus for 14 disks of insulation, a 230-kv. arrester will hold the potential to 1200 kv., which is 200 kv. more than if an arrester is used on each circuit. The arrester current with the arrester on the bus is about 2800 amp. compared with 1800 amp. when two arresters are used. It must be remembered that this condition only applies when the circuits are such that impulses can arrive from each circuit at the arrester at the same time. Thus for the first time it is possible to evaluate accurately the advantage of the use of one arrester on the bus compared to one arrester for each circuit. If more than two circuits can deliver impulses to the same bus at the same time, additional curves must be drawn for that condition.

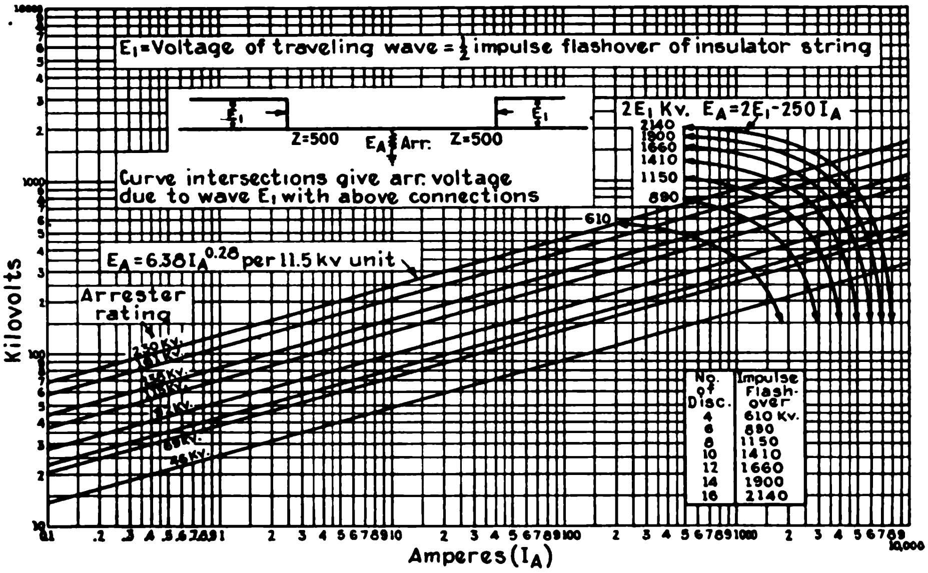

Fig. 12. Grounded Neutral Thyrite Arrester Characteristics with Traveling Waves

(Arrester connected to receive two simultaneous impulses.)

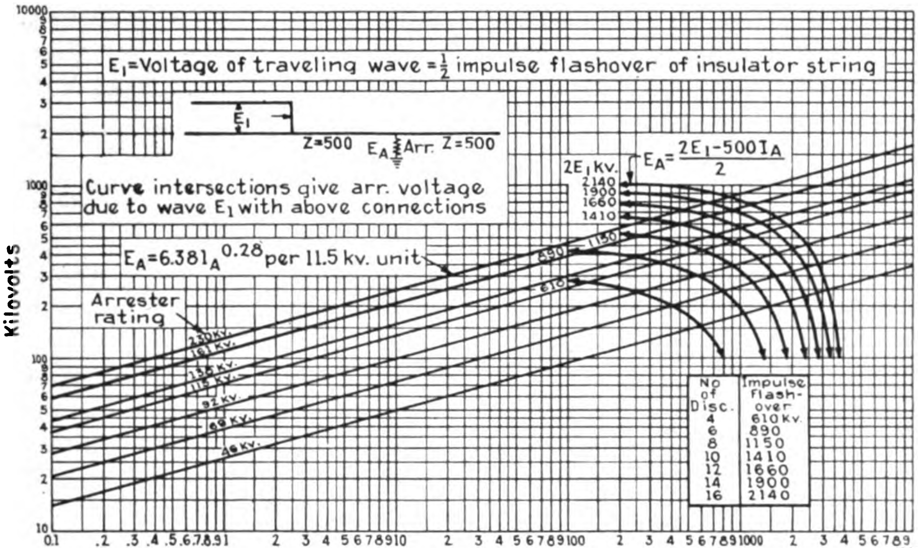

Fig. 13. Grounded Neutral Thyrite Arrester Characteristics with Traveling Waves

(Arrester connected to receive impulses in one direction, with outgoing circuit in another direction.)

If, on the other hand, the circuits are so arranged that impulses travel to the arrester from one direction with outgoing circuits in another direction, the arrester's potential will be correspondingly reduced. Such a condition is illustrated in Fig. 13, where the arrester is considered as being on a bus with one incoming and one outgoing line perhaps in opposite directions. Using the same example as before of a 230-kv. arrester with 14 disks of insulation, the arrester potential is 800 kv. with a current of 650 amp. flowing through the arrester.

By similar methods the arrester potential can be calculated for almost any assumed circuit condition so that arrester protection performance can be predicted accurately.

The condition of direct stroke, if occurring within one span length of the arrester but with an insulator string in between, has been assumed to be equivalent to that of a traveling wave having a potential equal to the insulator flashover, such as might result from an induced potential of twice the insulator flashover. On the assumed 230-kv. circuit, this potential is nearly 4,000,000 volts, which is much in excess of any potential yet indicated by the surge investigations on such a line. Curves similar to those of Fig. 11 show that under such an extreme condition the arrester potential would be 1300 kv., which is still safe for the modern transformer. It seems certain that such potentials could occur only in connection with direct strokes very close to the point of connection of the arrester to the transmission line and could not represent a possible induced condition with present insulation levels.

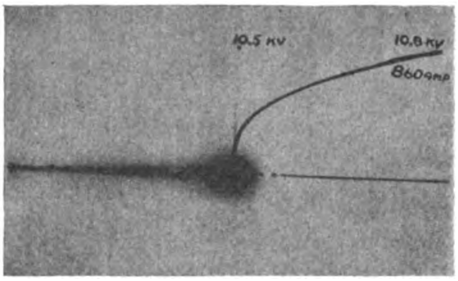

Fig. 14. Volt-ampere Characteristic of 3000-volt Thyrite Lightning Arrester. Gap sparks in one microsecond

The Arrester Unit

The arrester unit for 11.5-kv. grounded neutral service as designed at present is 14½ in. high and 12 in. in dia. It weighs about 100 lb. The unit is sealed, as no venting is necessary with this new arrester. No testing is necessary by the customer, but if he does wish to check the arrester's characteristic, it can be done by the use of the ordinary oscillograph. If arrangements are made to measure voltage and current by the use of the oscillograph, a few cycles of 60-cycle current can be made to pass through the arrester and from the oscillogram, showing voltage and current, the arrester's characteristic can be determined accurately. Such a test cannot be prolonged as the arrester would become hot and the series gaps would be burned.

Distribution Arrester

In the distribution arrester Thyrite disks one inch thick and three inches in diameter are used. The 3-kv. arrester requires two disks in series. It has a volt-ampere characteristic designed to be similar to the station type arrester for the same rating. Thus at 1000 amp. the arrester potential is 2.8 times the arrester rating. Since the distribution arrester is provided with but one-fourth of the area of the station type, it has but one-fourth of the current-carrying capacity. A cathode-ray oscillogram giving the volt-ampere characteristic for the 3-kv. arrester is shown in Fig. 14, and, like Fig. 10, it shows how accurately the volt-ampere curve checks with the calculated curve pro-rated from Fig. 11.

Transmission Line Type Arrester

Probably the least reliable part of electric transmission is the transmission line itself during lightning storms. No transmission line has yet been built which is proof against lightning flashovers. The number of flashovers has been reduced by the use of ground wires and extra insulation, but they have not yet been eliminated. From the standpoint of interruption to service, two methods of attack are available: one to render the flashover innocuous by the use of such devices as the fused grading ring or the Peterson coil, and the other to prevent the flashover by whatever means possible.

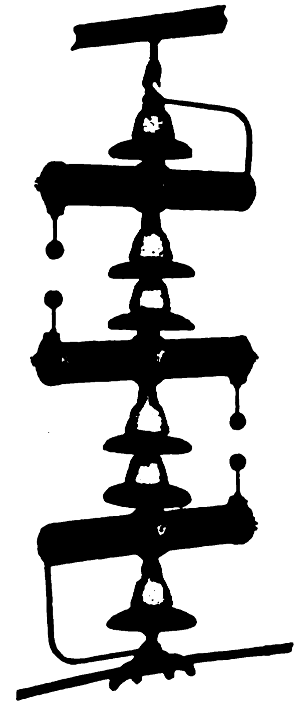

Fig. 15. 69-kv. Transmission Line Lightning Arrester

The better method is to prevent the flashover and if possible at the same time to absorb a considerable portion of the energy of the charged capacity of the line by the use of some device, such as a lightning arrester.

The idea of using arresters along a line is not new but suitable arresters have not been available either from the standpoint of size or cost.

The new arrester material will, it is believed, offer a means of protecting insulator strings on towers at a cost which is reasonable; and it should greatly increase the reliability of transmission lines.

The problem is more definite than that of protecting station insulation, since the arrester is placed very close to the insulator string and both have the same ground.

An arrester using Thyrite disks for the protection of transmission line insulators is shown in Fig. 15. The arrester shown is rated at 69 kv. and uses 72 disks, three inches in diameter, and one inch thick, so that the protective characteristic would correspond to a station type rated 108 kv. According to Fig. 11, with a current of 2000 amp. flowing the arrester potential is about 500 kv., while the flashover for four insulators is 610 kv., or for six insulators is 890 kv.

It is probable that experience will show that the number of disks can be reduced, which will improve the protection afforded and also reduce the cost of the arrester.

With such an application of arresters it is not necessary that the arrester have large discharge capacity as several would operate in parallel. Whether such protection would eliminate flashovers due to direct strokes is not known. It is the intention to try out arresters of this character on at least two transmission lines next summer.

Failure Tests

Many careful tests have been conducted on low-voltage units of all three types in the factory, in which were supplied both 60-cycle power and impulses timed to strike at the most dangerous point on the wave.

In May 1929, a 66-kv. Thyrite station arrester was tested on a 66-kv. transmission line with the line energized at normal potential, the impulse being supplied with a million-volt portable generator. During the test the six units were reduced to four, which withstood many impulses with no signs of damage. As far as the author is aware this is the first time that a high-voltage arrester has been tested in this manner.

Later, in September 1929, a similar test was carried out on a 132-kv. transmission line with over 100,000 kv-a. available, again using a million-volt impulse generator. In this case the number of units was reduced to seven, the line to ground potential being 77 kv., and again the arrester showed no signs of any weakness; and an examination of the gaps in each unit after the tests showed practically no effect of the discharges.

Because of the complete tests made, both from the protective standpoint and the failure standpoint, the arrester is being applied for all voltages up to and including 132 kv. in a limited number of installations.

Conclusions

A new material has been developed called Thyrite, which has the property of increasing or decreasing its resistance as the voltage is decreased or increased. This relationship does not depend on the rate of voltage application and may be made to repeat itself indefinitely without change. The resistance and current relationships follow a definite law which can be expressed in the form of a simple hyperbolic equation. The characteristics of the material are defined by the exponent and constant taken from this hyperbolic equation. This change in resistance is such that the current increases 12.6 times each time the applied voltage is doubled.

Thyrite can be manufactured successfully from the standpoint of duplication with proper control of materials and processes. It can be produced in any shape which can be successfully molded. The effect of increased temperature is to slightly decrease its resistance for any given voltage.

This material is well adapted for use in a protective device; lightning arresters in three different forms are now being tested in service.

The station arrester is made in 11.5-kv. sections which are assembled in the field in a manner similar to pedestal insulators. These units are self-contained and do not require a series gap. An arrester for grounded neutral 69 kv. service is approximately 87 in. high. For currents up to 1000 amp. the potential across the arrester will not exceed 2.8 times the arrester rating in crest volts.

The protective characteristics of the distribution arrester are similar to those of the station-type arrester, although its impulse current capacity is but one-quarter of that of the station type.

The great advantages of the new arresters lie in their permanence, small size, low installation cost, small weight and the predictability of the results to be expected for any given condition.

A new type of arrester for protection of the transmission line against flashover is being developed, which is incorporated in the insulator string. This arrester is designed not only to prevent the flashover of the insulator string, but also to absorb a considerable portion of the energy of the discharge.

Laboratory experience with the cathode ray oscillograph gives definite knowledge of the protective characteristics which can be calculated for any given circuit condition, while tests in the field on high-voltage transmission lines with portable impulse generators have successfully demonstrated the ability of the arrester to prevent the continuous flow of power current following the impulse.

The ability of an arrester to successfully withstand all of the exigencies of operation without failure cannot be completely determined in the laboratory. For this reason it is necessary for the arrester to pass through a certain period of trial in the field, which will help determine whether the factor of safety employed is proper. For several months arresters have been in service on lines up to 66 kv., and 110 and 132-kv. installations are soon to be made.

The author wishes to express his appreciation to Messrs. J. R. T. Craine, L. H. Whitney, and A. C. Campbell for their assistance in the development of Thyrite. Their help has been invaluable. Messrs. E. M. Duvoisin, E. G. Newton, and L. W. Evans have all had a large share in the development of the arrester, while to Mr. T. Brownlee the author is indebted for assistance in the preparation of this article.

The Effect of Corona on Ground-wire Protection of Power Transmitting Circuits

Early Calculations Neglecting Corona—Test Results Indicate Better Protection—Subsequent Calculations Accounting for Corona—Check Test Results

By E. M. HUNTER
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IT is generally conceded that overhead ground wires, when properly installed, will reduce the magnitude of induced lightning voltages on transmission lines. However, there is considerable discrepancy between authorities as to the amount of protection to be expected. There is a fairly general agreement as to the theoretical protection, as calculated from the classical formulas; but the results of tests by F. W. Peek, Jr., in the High Voltage Engineering Laboratory in Pittsfield show a much better protection than can be obtained from these formulas. C. A. Woodrow has offered an explanation of this as follows:

> The potential gradient at the surface of the conductors and ground wire under lightning conditions greatly exceeds the rupturing potential gradient of air. The air breaks down, forming corona, thus in effect enlarging the diameter of the conductors and ground wire. This in turn increases the capacitance between conductors and ground wire, and correspondingly decreases the induced voltage on the conductors.(1)

The formulas for obtaining the protective ratios of ground wires may be found in several articles and textbooks,(2) but these formulas in no way attempt to evaluate the effect of corona on the ground wires. The purpose of this article is to show a means by which the effects of corona on the ground wire may be included in the formulas.

The increased protection obtained from corona on the line conductors is negligible and may be neglected since laboratory tests and calculations have shown that corona is present to a much lesser degree on the line conductors than on the ground wires.

To obtain a clear understanding of the principles underlying the protection obtained from the use of overhead ground wires, it is necessary to consider the causes of transient overvoltages during lightning storms.

When a charged cloud is over a portion of a transmission line, an electrostatic field is established between the cloud and ground. Charges, of sign opposite to that of the cloud, will be on the conductors in the cloud field and on the earth. With the collapse of the electrostatic cloud field, due to the discharge of lightning, the charge which was bound by the cloud field is set free and begins to travel along the transmission line. The voltage which appears on the transmission line will depend upon the capacitance between the line and ground. It would be equal to the potential gradient of the cloud field multiplied by the height of the line above earth if the circuit were without ground wires. The presence of the ground wires increases the capacitance to earth; and with cloud gradients sufficient to cause corona, the capacitance is further increased as the effective diameter of the ground wire is increased.

The maximum induced potential has been estimated by Peek,(3) Noinder, and others to be about 100 kv. per ft. of height of conductor. Voltages indicating a maximum gradient of about 60 kv. per ft. have been recorded with the Surge Voltage Recorder during lightning storms.

The principle involved in the protection obtained from overhead ground wires reverts to Faraday's original proposition: to protect anything from lightning or electrostatic influences, surround it with a grounded cage. The ground wire is simply a small approach to that condition. Corona on the ground wire, by increasing the effective diameter of the wire and bringing the ground nearer to the line conductors, increases the protection afforded by the ground wires.

The procedure in estimating ground-wire protection will be outlined by determining the protection obtained from two ground wires installed over three line conductors.

Before the cloud is discharged, the conductors and ground wires will have bound charges of sign opposite to that of the charge on the cloud. The potential of a wire due to the charge on the cloud is equal to the cloud field gradient (G) multiplied by the height of the wire above ground. The potential of a wire due to the bound charges on it and adjacent wires is not so easily evaluated. For convenience of calculation, the surface of the earth is assumed to be an equipotential plane at zero potential. The charge on the earth's surface may therefore be replaced by a charge of opposite sign on an imaginary conductor, parallel to the overhead conductor and at an equal distance below the surface of the earth. The imaginary conductor is known as the image of the overhead conductor. The conductors and their images are shown in Fig. 1.

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(1) W. W. Lewis: *Transmission Line Engineering*, p. 242, McGraw-Hill.

(2) E. E. F. Creighton, "Theory of Ground Wires," *Trans. A.I.E.E.*, 1916, p. 948.
E. J. Berg, *Electrical Engineering*, Advanced Course, McGraw-Hill.

(3) F. W. Peek, Jr., "High Voltage Phenomena," *Jour. Frank. Inst.*, Jan., 1924.

Referring to Fig. 1, if we should remove all of the charges on the conductors except that on conductor *No. 2*, the potential of conductor *No. 1* due to the charge on conductor *No. 2* is given by the expression

$$V_1 = 2\, Q_2 \log_e \frac{r_1}{r_2}$$

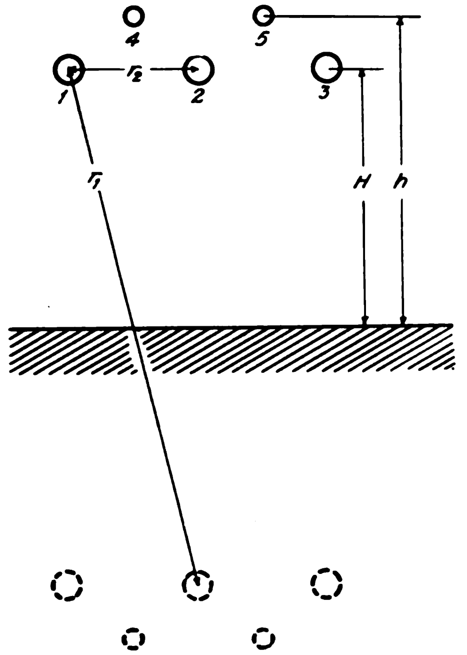

Fig. 1. Conductor Arrangement of Single-circuit Line with Two Ground Wires

where

V_1 = the potential of conductor *No. 1*.

Q_2 = the charge on conductor *No. 2*.

r_1 = the distance from conductor *No. 1* to the image of conductor *No. 2*.

r_2 = the distance from conductor *No. 1* to conductor *No. 2*.

The expression $2 \log_e \frac{r_1}{r_2}$ is known as Maxwell's mutual potential coefficient between conductor *No. 1* and conductor *No. 2*, and may be expressed as $P_{1\cdot 2}$. If all of the charges were removed except on one wire, each in turn, similar expressions may be written for the potential of conductor *No. 1*. The potential coefficient obtained when the charge is left on *No. 1* conductor is

$$P_{1\cdot 1} = 2 \log_e \frac{2H}{r}$$

where

H = the height of conductor *No. 1* above ground.

r = the radius of the conductor *No. 1*.

It is readily seen from the geometrical relations of Fig. 1 that $P_{1\cdot 2} = P_{2\cdot 1}$, etc., and all of Maxwell's potential coefficients are positive numbers.

The potential of conductor *No. 1* with all of the charges on the wires is the algebraic sum of all of the individual potentials due to the charges on each of the conductors.

In the problem under consideration, before the cloud is discharged, the algebraic sum of the potentials on each wire due to the cloud field and the charges on the conductors is zero. In considering these potentials, the normal-frequency line voltages have been neglected.

These equations may be written as follows:

$$V_1 = 0 = GH + P_{1\cdot 1} Q_1 + P_{1\cdot 2} Q_2 + P_{1\cdot 3} Q_3 + P_{1\cdot 4} Q_4 + P_{1\cdot 5} Q_5 \quad (1)$$

$$V_2 = 0 = GH + P_{2\cdot 1} Q_1 + P_{2\cdot 2} Q_2 + P_{2\cdot 3} Q_3 + P_{2\cdot 4} Q_4 + P_{2\cdot 5} Q_5 \quad (2)$$

$$V_3 = 0 = GH + P_{3\cdot 1} Q_1 + P_{3\cdot 2} Q_2 + P_{3\cdot 3} Q_3 + P_{3\cdot 4} Q_4 + P_{3\cdot 5} Q_5 \quad (3)$$

$$V_4 = 0 = Gh + P_{4\cdot 1} Q_1 + P_{4\cdot 2} Q_2 + P_{4\cdot 3} Q_3 + P_{4\cdot 4} Q_4 + P_{4\cdot 5} Q_5 \quad (4)$$

$$V_5 = 0 = Gh + P_{5\cdot 1} Q_1 + P_{5\cdot 2} Q_2 + P_{5\cdot 3} Q_3 + P_{5\cdot 4} Q_4 + P_{5\cdot 5} Q_5 \quad (5)$$

The discharge of the cloud removes the cloud gradient and the voltages of the line conductors depend upon the bound charges. The cloud discharge has been assumed to be instantaneous and the ground wires and earth are at zero potential. To keep the ground wires at zero potential, these wires must be sufficiently grounded in order that the charges on them before cloud discharge (Q_4 and Q_5) may be replaced with new charges (Q_4' and Q_5') from earth to keep them at zero potential.

The equations after cloud discharge are:

$$V_1 = P_{1\cdot 1} Q_1 + P_{1\cdot 2} Q_2 + P_{1\cdot 3} Q_3 + P_{1\cdot 4} Q_4' + P_{1\cdot 5} Q_5' \quad (6)$$

$$V_2 = P_{2\cdot 1} Q_1 + P_{2\cdot 2} Q_2 + P_{2\cdot 3} Q_3 + P_{2\cdot 4} Q_4' + P_{2\cdot 5} Q_5' \quad (7)$$

$$V_3 = P_{3\cdot 1} Q_1 + P_{3\cdot 2} Q_2 + P_{3\cdot 3} Q_3 + P_{3\cdot 4} Q_4' + P_{3\cdot 5} Q_5' \quad (8)$$

$$V_4 = 0 = P_{4\cdot 1} Q_1 + P_{4\cdot 2} Q_2 + P_{4\cdot 3} Q_3 + P_{4\cdot 4} Q_4' + P_{4\cdot 5} Q_5' \quad (9)$$

$$V_5 = 0 = P_{5\cdot 1} Q_1 + P_{5\cdot 2} Q_2 + P_{5\cdot 3} Q_3 + P_{5\cdot 4} Q_4' + P_{5\cdot 5} Q_5' \quad (10)$$

If the circuit were without ground wires, the potential of the line wires would be:

$$V = -GH \quad (11)$$

The protective ratio (P.R.) is defined as the ratio of the induced voltage obtained with ground wires to the induced voltage obtained without ground wires. Thus by subtracting Equations (6) from (1) and (7) from (2) and dividing by Equation (11), we obtain the protective ratios for the outside and middle conductors.

$$\text{P.R. (Outside Conductor)} = 1 - \frac{h}{H}\left(\frac{P_{1\cdot 4} + P_{1\cdot 5}}{P_{4\cdot 4} + P_{4\cdot 5}}\right) \quad (12)$$

$$\text{P.R. (Middle Conductor)} = 1 - \frac{h}{H}\,\frac{2\, P_{2\cdot 4}}{(P_{4\cdot 4} + P_{4\cdot 5})} \quad (13)$$

So far in these calculations, the formation of corona on the ground wires has been neglected. On most high-voltage transmission lines, corona appears on the ground wires at a very low cloud gradient. The formation of corona depends upon the charge on the wire. The charges on the ground wires may be determined by solving Equations (1), (2), and (4), since from the symmetrical relations of the line $Q_1=Q_3$ and $Q_4=Q_5$. Solving these equations by determinants, the charge on the ground wire is

$$Q_4=\frac{G\begin{vmatrix} -H & P_{1\cdot 2} & (P_{1\cdot 1}+P_{1\cdot 3}) \\ -H & P_{2\cdot 2} & (P_{2\cdot 1}+P_{2\cdot 3}) \\ -h & P_{4\cdot 2} & (P_{4\cdot 1}+P_{4\cdot 3}) \end{vmatrix}}{\begin{vmatrix} (P_{1\cdot 4}+P_{1\cdot 5}) & P_{1\cdot 2} & (P_{1\cdot 1}+P_{1\cdot 3}) \\ (P_{2\cdot 4}+P_{2\cdot 5}) & P_{2\cdot 2} & (P_{2\cdot 1}+P_{2\cdot 3}) \\ (P_{4\cdot 4}+P_{4\cdot 5}) & P_{4\cdot 2} & (P_{4\cdot 1}+P_{4\cdot 3}) \end{vmatrix}}=G\frac{D'}{D} \quad (14)$$

The distance above ground H and h should be expressed in centimeters.

The gradient at the surface of the ground wire may be obtained from the expression

$$G_s=\frac{2Q_4}{r} \quad (15)$$

where

G_s = the gradient at surface of the ground wire.
Q_4 = the charge on the ground wire.
r = the radius of the ground wire.

The visual corona gradient at the surface of a wire is given by the expression.⁽⁴⁾

$$G_v=29.8\left(1+\frac{0.301}{\sqrt{r}}\right)\text{ kv./cm.} \quad (16)$$

where

G_v = the visual corona gradient.
r = the radius of the wire.

Thus the cloud gradient that will give visual corona on a wire may be obtained from Equations (14), (15), and (16) and is

$$G=\frac{r\,G_v\,D}{2\,D'}\text{ kv./cm.} \quad (17)$$

In the protective ratio Equations (12) and (13), Maxwell's potential coefficient is $P_{4\cdot 4}=2\log_e\frac{2h}{r}$. If the radius of the ground wire (r) is increased, the protective ratio will be lower. Corona on the ground wire will increase the effective radius of the wire.

In order to present the effects of corona on ground-wire protection in a usable formula, it was necessary to assume that the new diameter of the ground wire is determined by corona before cloud discharge. This assumption allows us to disregard the difference between positive and negative corona, time lag of corona, and the fact that corona is not constant during cloud discharge and may be different before and after cloud discharge.

In evaluating the effects of corona, it is assumed that the radius of the ground wire before cloud discharge is increased to a size such that corona is just visible and this increased diameter is used for determining the protective ratio. Thus at any definite cloud gradient there is a certain radius of ground wire which will permit corona to just appear. This radius may be determined from Equations (16) and (17).

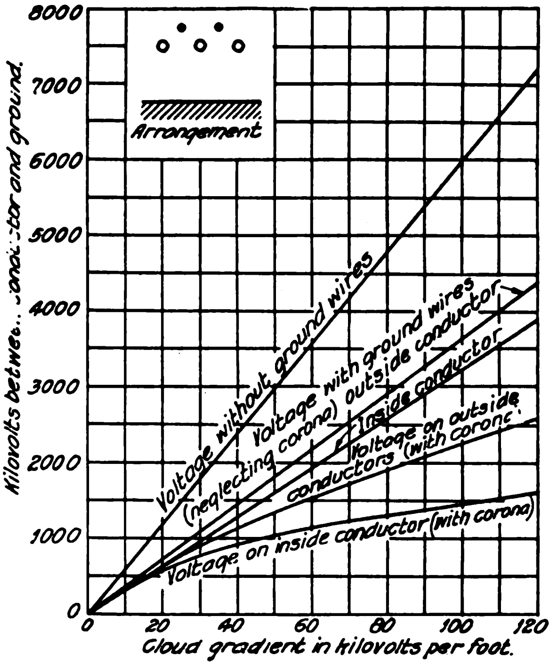

Fig. 2. Potential Between Conductor and Ground for Various Cloud Gradients

$$\text{Protective ratio}=\frac{\text{Voltage with ground wires}}{\text{Voltage without ground wires}}$$

With this new radius, a protective ratio may be found which corresponds to the cloud gradient assumed. In an actual numerical problem, it simplifies the labor somewhat by working backward; *i.e.*, by assuming the new radius of the ground wire and solving for the cloud gradient and the protective ratio.

The protective ratios obtained by using the heights above ground and conductor spacing of a 220-kv. line equipped with two ground wires are shown in curve form in Fig. 2. From these curves it is seen that the protective ratio is not a constant for any given conductor arrangement but varies with the cloud gradient; the higher the cloud gradient, the greater the protection that is obtained.

Comparative estimated values of protective ratios at a 100-kv. per foot cloud gradient for various arrangements of 220-kv. lines are listed in Table I. These values are given with considerable apparent accuracy. As the calculations are based upon the ideal conditions of zero time for cloud discharge, zero

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⁽⁴⁾F. W. Peek, Jr.: *Dielectric Phenomena in High-voltage Engineering*, McGraw-Hill.

tower footing resistance, etc., the actual protection obtained in practice may be somewhat lower than the calculations indicate.

TABLE I

PROTECTIVE RATIOS OF GROUND WIRES

Arrangement	Conductor	Protective Ratio	Per Cent Decrease in Induced Voltage
● O O O 1 2 3	(1)	0.57	43
	(2)	0.47	53
	(3)	0.57	43
● ● O O O	(1)	0.38	62
	(2)	0.25	75
	(3)	0.38	62
● ● ● O O O	(1)	0.31	69
	(2)	0.24	76
	(3)	0.31	69
● O O O O O O	(1)	0.46	54
	(2)	0.52	48
	(3)	0.56	44
● ● O O O O O O	(1)	0.27	73
	(2)	0.33	67
	(3)	0.40	60

O Indicates conductor.
● Indicates ground wire.

$$\text{Protective Ratio} = \frac{\text{Voltage with ground wire}}{\text{Voltage without ground wire}}$$

It is very difficult to verify the amount of protection afforded by ground wires on transmission lines except by a comparison of operating experience with and without ground wires. W. W. Lewis, in his article, "Transmission Line Insulation and Field Tests Pertaining to Lightning," in the July, 1929, issue of this magazine, gives protective ratios, estimated from surge voltage recorder data, which agree with the protective ratios obtained by Peek from his miniature lines in the High Voltage Laboratory in Pittsfield.(6) There is also a fairly general agreement between Peek's values of protective ratios and those obtained by the formulas just explained, especially at the higher voltage gradients.

Summary

The procedure in determining the theoretical protective ratio of a system of line and ground wires is as follows:

(1). Set up the equations for the electrostatic conditions before and after cloud discharge and determine the equations from the protective ratios, similar to Equations (1) to (13).

(2). Assume increases in the size of the ground wire and calculate the gradients which would cause this increase in size of wire from Equations (14), (16), and (17).

(3). With the increase in radius, determine the potential coefficient ($P_{4\cdot4}$) and the new protective ratios from equations similar to Equations (12) and (13).

Acknowledgment

The writer wishes to acknowledge the many helpful suggestions of Mr. W. W. Lewis, under whose direction this investigation was carried out.

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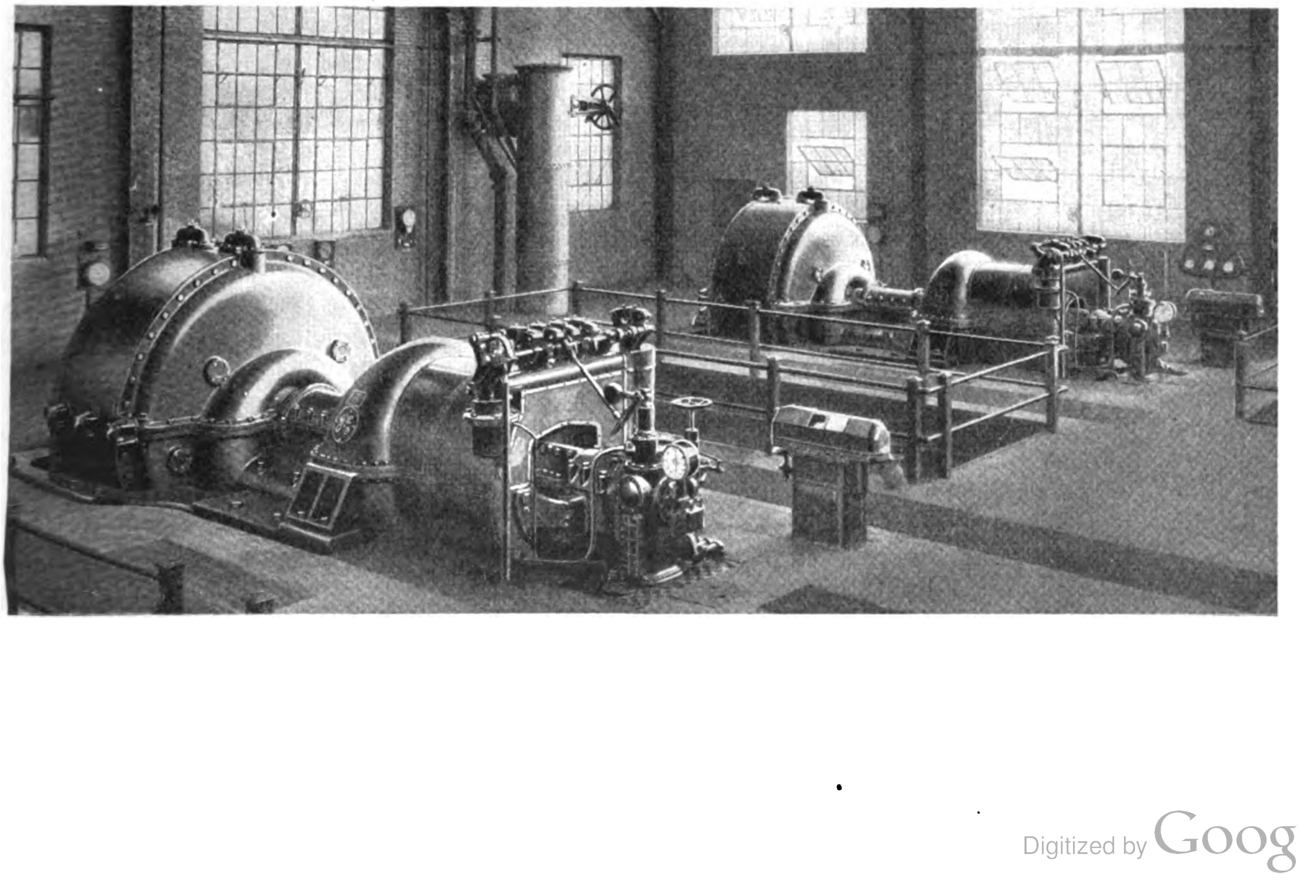
(6) F. W. Peek, Jr., "Lightning and Other Transients on Transmission Lines," *Trans. A.I.E.E.*, 1924, p. 1205.

Turbine-driven Blast Furnace Blowers



Substation Ventilation

Prevention of Preheated Air Entering Machine—Types of Housings for Synchronous Converters—D-c. and A-c. Machines—Station Design

By G. SOHLBERG

Construction Engineering Department, General Electric Company

THE air temperatures in a substation equipped with open machines varies from that of the outside air entering the building to that of the heated air ejected from the machines.

The machines themselves being the source of heat are surrounded by the warmest air, and air at some temperature between this and that of the entering air escapes through the ventilators or other outlets in the building.

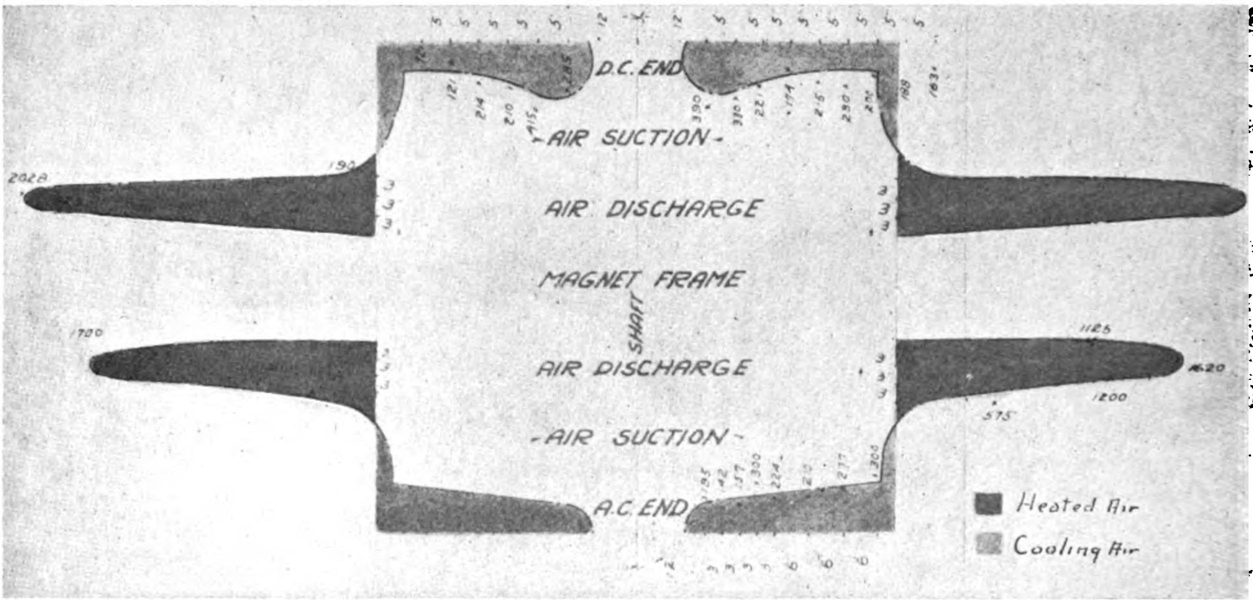


Fig. 1. Diagram Showing Air Velocities at Center Line Elevation Above Inside Line of Base Casting of a Standard Synchronous Converter. Values on the chain line represent horizontal velocities in f.p.m. and are outward where this line falls outside the base line and inward where it falls inside

Practically the only force acting to eject the heated air from the building is the chimney effect working on the average density difference between the indoor and outdoor air. At prevailing temperatures this force is so small that either very large inlet and outlet openings must be provided to obtain adequate ventilation or relatively high temperatures must be allowed to exist in the station. Both of these conditions are objectionable and can be avoided by installing means to collect the hottest air as discharged from the machines and conducting it outdoors. Such means in the case of d-c. machines assumes the shape of volute housings surrounding the armatures and for a-c. machines concentric housings surrounding the stator frames, either type being connected to ducts leading outdoors or to air coolers if cooling water is available at low cost.

Synchronous Converters and D-c. Machines

Close observation of the air pressures immediately surrounding a synchronous converter or d-c. machine in operation will reveal that partial vacua exist at the ends of the armature and relatively high pressures around the circumference of it. The relative magnitude of these pressures generated by a standard machine at shaft elevation, vertically above the inside line of the base casting, are shown in Fig. 1. It can be further shown, by means of streamers or smoke bombs, that the heated air is discharged tangentially from the armature surface. The outward flow from the middle section is obstructed by the poles and magnet frame which divides the discharge into two pressure belts, which widen out and weaken in intensity as the distance from the armature increases. At the ends of the armature, where the radial and longitudinal conductors join, the path of air flow takes the shape of long-pitch spirals bending around in torus form over the joint. This effect is discernible at some distance from the armature as illustrated in Fig. 2 which also shows other paths of air flow around a standard machine. Thus the inertia or velocity head imparted to the air by the armature is such that only part of it is carried beyond the direct influence of the low pressure regions. The remainder follows the path of least resistance, as would naturally be expected, flowing to these regions and returning to the machine, the make-up being supplied from the general room air. Thus the machine is supplied with preheated air for cooling!

The same general characteristics of air flow may be observed immediately surrounding a free fan impeller; *e.g.*, the air ejected from the vane surface travels only a short distance before it gradually turns over to return to the suction areas at the ends, as in Fig. 3. Its effect on such inlet or outlet openings as may be provided in the building walls and roof is practically nil. On the other hand, if this impeller is surrounded with a scroll as shown in Fig. 4, having its discharge opening connected to ducts leading outdoors the path of air flow would be different. The entire quantity of air entering at the ends of the impeller would be conducted away from it and the make-up could only be supplied through the inlet openings of the building or enclosure.

So also with the revolving element of a machine. It can be enclosed in a similar housing serving in this case to collect the heated air (see Figs. 5 and 6), and equipped with similar ducts to conduct it outdoors. Very little if any of the losses would then be dissipated into the room air, and consequently the temperature of this air would remain practically the same as that of the incoming cooling air entering the building through openings provided for that purpose. The air entering the machines at the ends would also be at this temperature, rather than at some higher temperature as now under commonly existing conditions; the difference depending on the amount of recirculation in the latter case and it, in turn, on the effectiveness of building ventilation. Since, by the nature of things, the quantity of air actually coming in contact with the heated surfaces of the machines is the same in either case, the cooler the air the cooler must the machine also be.

More or less successful attempts to keep d-c. generators and synchronous converters properly cooled have been made by providing air intake hoods over the coupling end of generators and over the commutator end of synchronous converters, an outlet hood being provided on the opposite side of the magnet frame. External blowers are in such cases employed to supply the necessary cooling air. Fig. 7 shows a schematic representation of this arrangement. So far as the movement of air is concerned, this design would be equivalent to one employing two blowers in series partly opposing one another. The first or low-pressure blower is thus one of ordinary design, the second or high-pressure blower representing the machine, and consisting of an ordinary impeller with a closed concentric side outlet scroll, but so assembled that a considerable portion of the impeller projects through on either side. This arrangement is schematically indicated in Fig. 8. In order to establish any appreciable flow of air through an assembly of this nature, the first blower would not only have to be designed for sufficient pressure at the rated capacity to overcome the resistance of the duct system, but also the far greater resistance of that portion of the impeller in the second blower which projects into the intake hood. The arrows in Fig. 8 indicate the probable paths of air flow in the inlet and outlet hoods of the high-pressure blower.

Obviously more efficient use of the equipment would be made in an assembly such as shown in

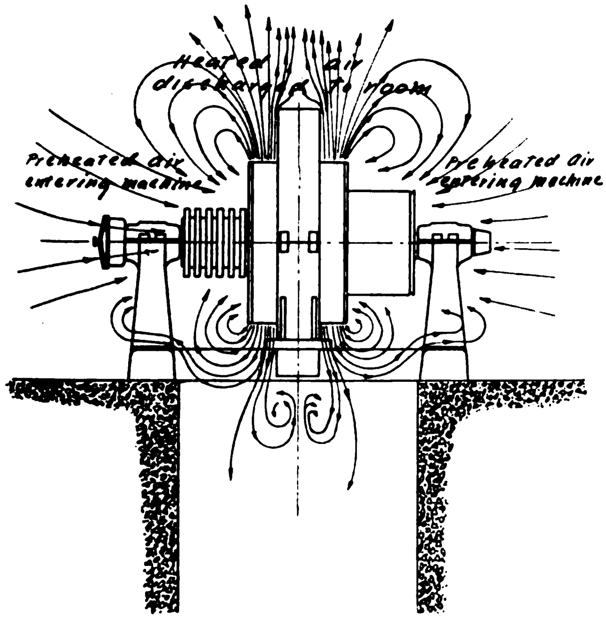

Heated air discharged to room
Preheated air entering machine
Preheated air entering machine

Fig. 2. Diagram Showing Direction of Air Currents Immediately Surrounding a Standard Synchronous Converter. Note recirculation giving maximum windage losses

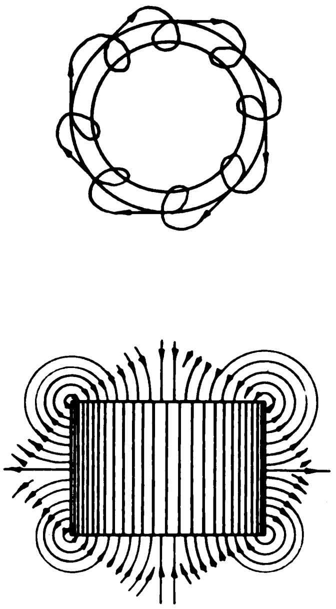


Fig. 3. Diagram of Air Flow Around the Impeller of an Ordinary Blower with the Housing Removed, Giving Maximum Windage and Maximum Recirculation

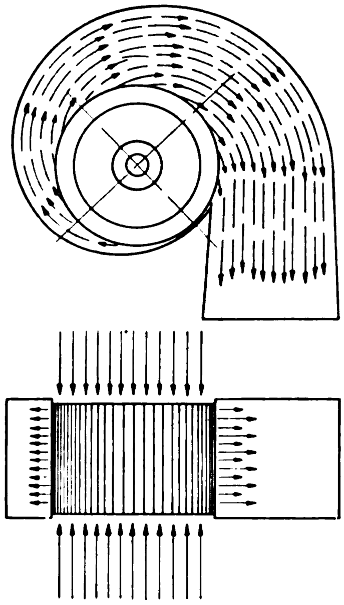


Fig. 4. Diagram of Air Flow Around and Inside an Ordinary Blower, Giving Minimum Windage and Recirculation

Fig. 9, where the fan action of the armature boosts rather than bucks the supply fan. For equal cooling the machine would require the same amount of air, but supplied at lower pressures; the energy consumption, therefore, would only be a fraction of that required with the former arrangement.

The logical conclusion from these observations lead us to a method of ventilation in which the revolving element of the generator or converter is employed as the impeller of a blower properly located within a suitably shaped scroll or housing, as indicated in Figs. 5 and 6. The fan effect thus established has been found

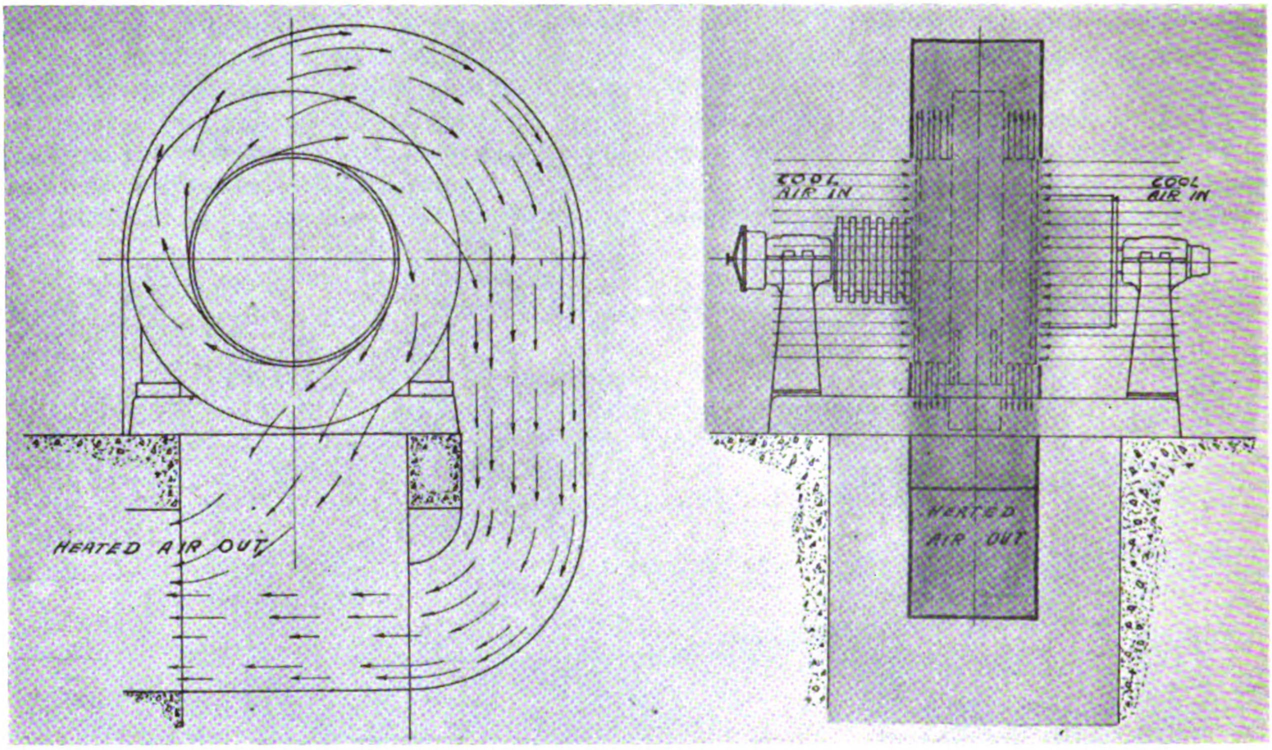


Fig. 5. Diagram Showing Air Flow Around a Standard Synchronous Converter Partly Enclosed in Fan-type Housing Employing the Armature as Impeller Resulting in Low Windage Losses and Practically No Recirculation

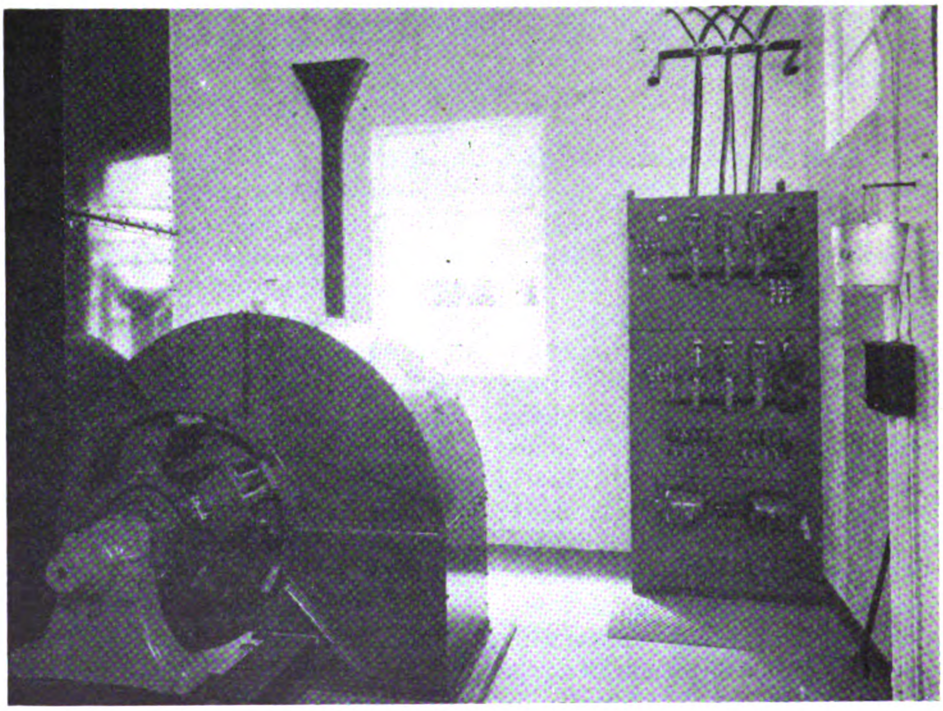


Fig. 6. Synchronous Converter with Volute-type Ventilating Housing and Duct for Collecting Heated Air and Conducting It Outdoors. Note free access to commutator and brushes

to be entirely adequate for the proper ventilation or cooling of the machine, drawing from the general room air supply and discharging through ducts to the exterior atmosphere.

Whether this fan effect must be supplemented by means of ordinary blowers acting in series with it, depends on the additional resistance against air flow introduced into the circuit. Generally speaking, supplementary blowers will be required when air washers, filters, long ducts, or apparatus introducing resistances of similar magnitude are employed. Again, whether they should be used as such to maintain a slight pressure within the building or be employed as exhausters, depends on the station design and local conditions. For instance, if the external air is contaminated with dust, flying sand, acid vapor or other matter in suspension, it might be well to use blowers and maintain pressure within the building so as to avoid inward leakage of such contaminated air. Under these conditions a basement is usually provided for the installation of the air cleaning equipment and blowers. On the other hand, when the air does not need cleaning and the hot air discharge duct must be made rather long or small in cross-section, the best results will be obtained with exhausters.

Where water is available at low cost, it is of advantage to use it as the cooling medium. Air coolers are then employed to transfer the heat from the air to the water. The arrangement of apparatus in this event would be with the surface air cooler located in the discharge opening of the machine housing. The air after being cooled would be discharged to the room, ultimately returning to the machine, thus recirculating a confined quantity of air, which need have no

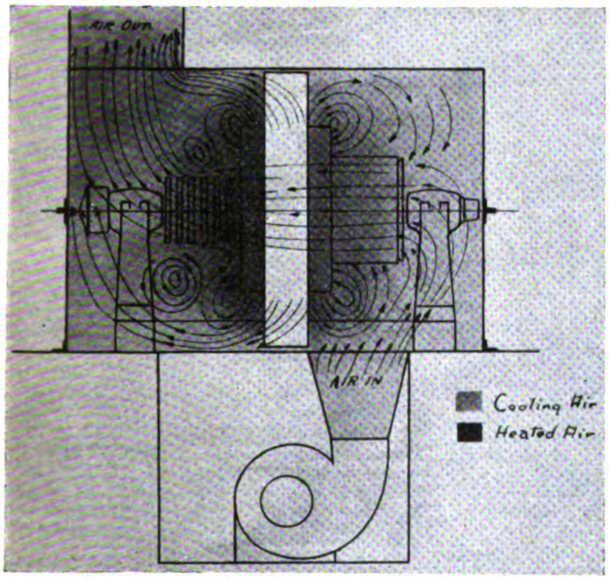


Fig. 7. Diagram Showing Paths of Air Flow within an Incorrectly Designed Housing of a Totally Enclosed Synchronous Converter. Note the opposing forces of the machine and the blower, also that the cooling air entering the machine is preheated

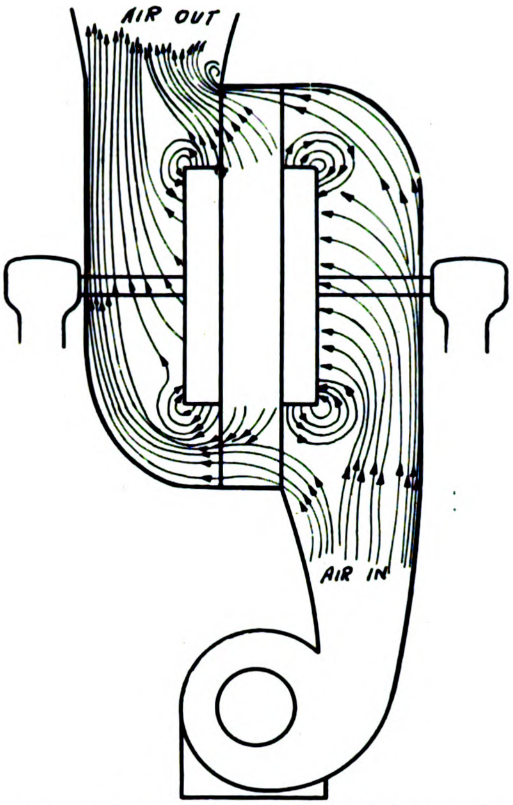


Fig. 8. Diagram Showing Probable Paths of Air Flow in the Inlet and Outlet Duct of a Blower Having a Concentric Side Outlet Housing and Wide Impeller Projecting Through Either Side

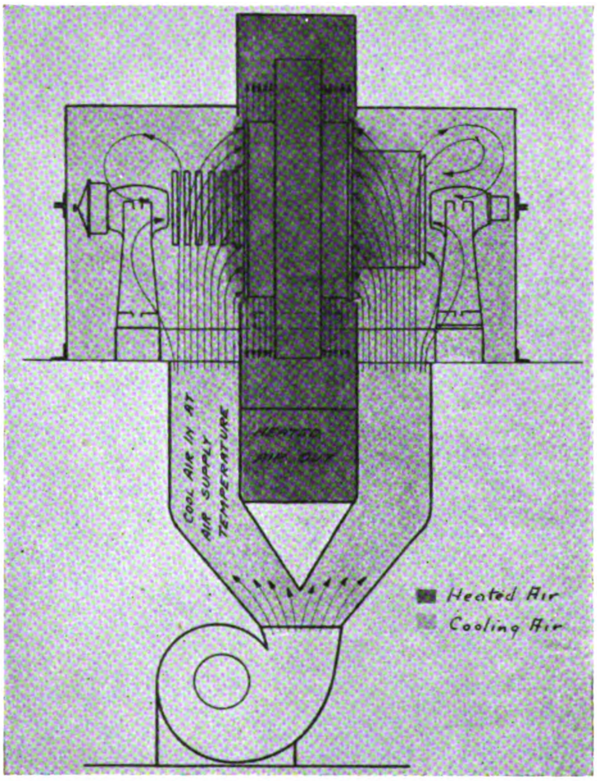


Fig. 9. Diagram Showing Paths of Air Flow Around Totally Enclosed Synchronous Converter Whose Armature is Employed as a Fan Impeller and Surrounded with Volute Scroll to Separate the Hot Air Discharge from the Cooling Air Entering the machine. Note that air enters machine at air supply temperature

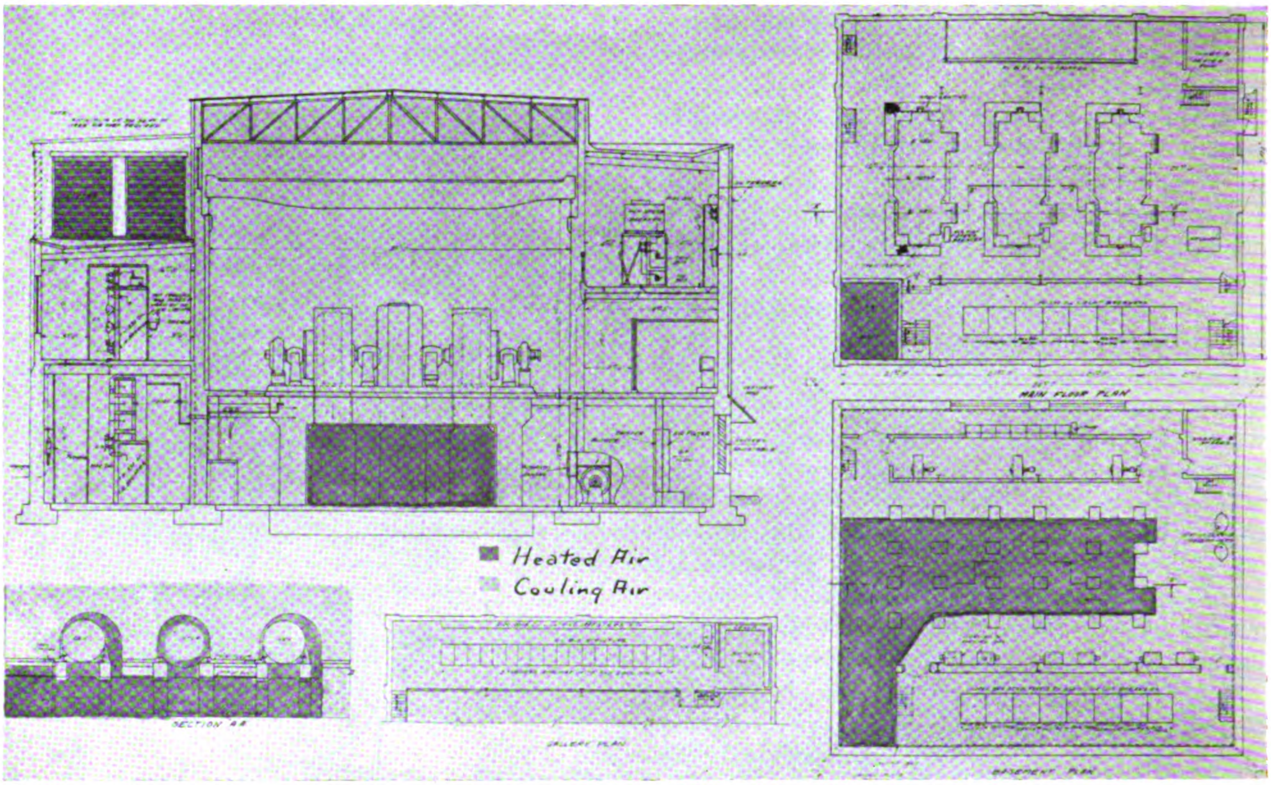

▨ Heated Air
▨ Cooling Air
SECTION A-A
GALLERY PLAN
MAIN FLOOR PLAN
BASEMENT PLAN

Fig. 10. Arrangement of Motor-generator Substation in which the Blower Action of the Machines is Employed to Eject the Heated Air. Plan and Sections

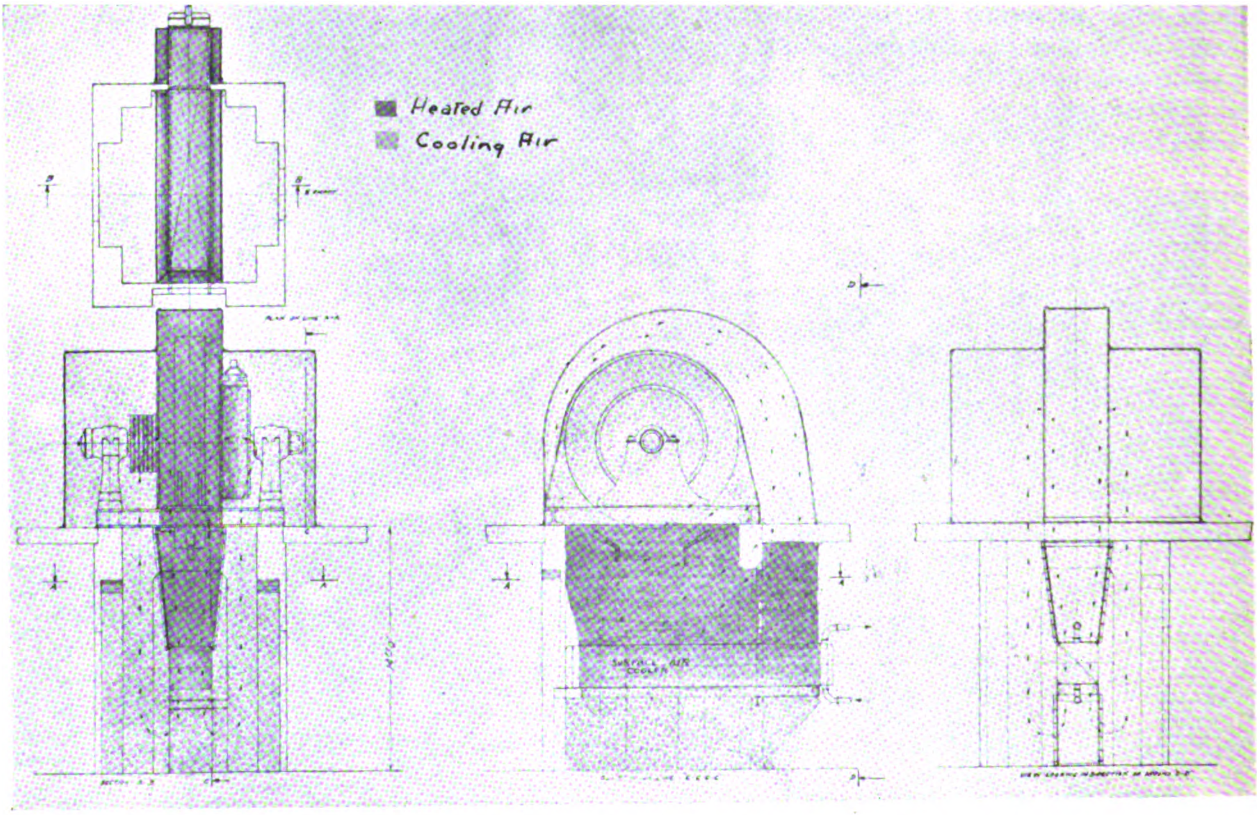

▨ Heated Air
▨ Cooling Air
SURFACE AIR COOLER

Fig. 11. Synchronous Converter with Surface Air Coolers. Plan and Elevations

communication with the external atmosphere. The quantity and temperature of available water supply, together with the temperatures of the air and machine, which it is desired to maintain, will determine whether the fan action of the machine need be supplemented by an exterior blower.

A-c. Machines

The heated air from a-c. machines is usually discharged through radial vents between the stator laminations into a concentric space provided for that purpose between the outside of such laminations and the machine frame. The frame is constructed with one or more openings for emitting the heated air from either the top, bottom, or sides. Machines not equipped with such receiving chambers can, of course, be easily surrounded with concentric housings to provide means for collecting this heated air. Cooling air enters at the ends as in d-c. machines.

In a great many existing installations the heated air is released into the room and naturally follows the path of least resistance returning to the ends. It is thus recirculated until the entire room temperature is raised to a level where the chimney effect acting on the average density difference dissipates the machine losses. Besides being uncomfortable to the operators this condition of high room temperatures makes the machines and other station equipment operate at far higher temperatures than necessary.

On the other hand, if the discharge openings are connected by means of ducts to the air outlets of the building, the heated air would be conveyed outdoors, the room air would stay at or near the inlet air temperatures, the cooling air entering the machine would also be at this temperature, and the machine itself with all the other equipment would operate at lower temperatures. Such ducts need in no way interfere with the access to the machine, nor with any arrangement whereby the machine losses may be used for heating during the heating season. Such an arrangement simply requires a damper in the duct to shut off the outdoor discharge, and an opening through which the heated air may be returned to the room.

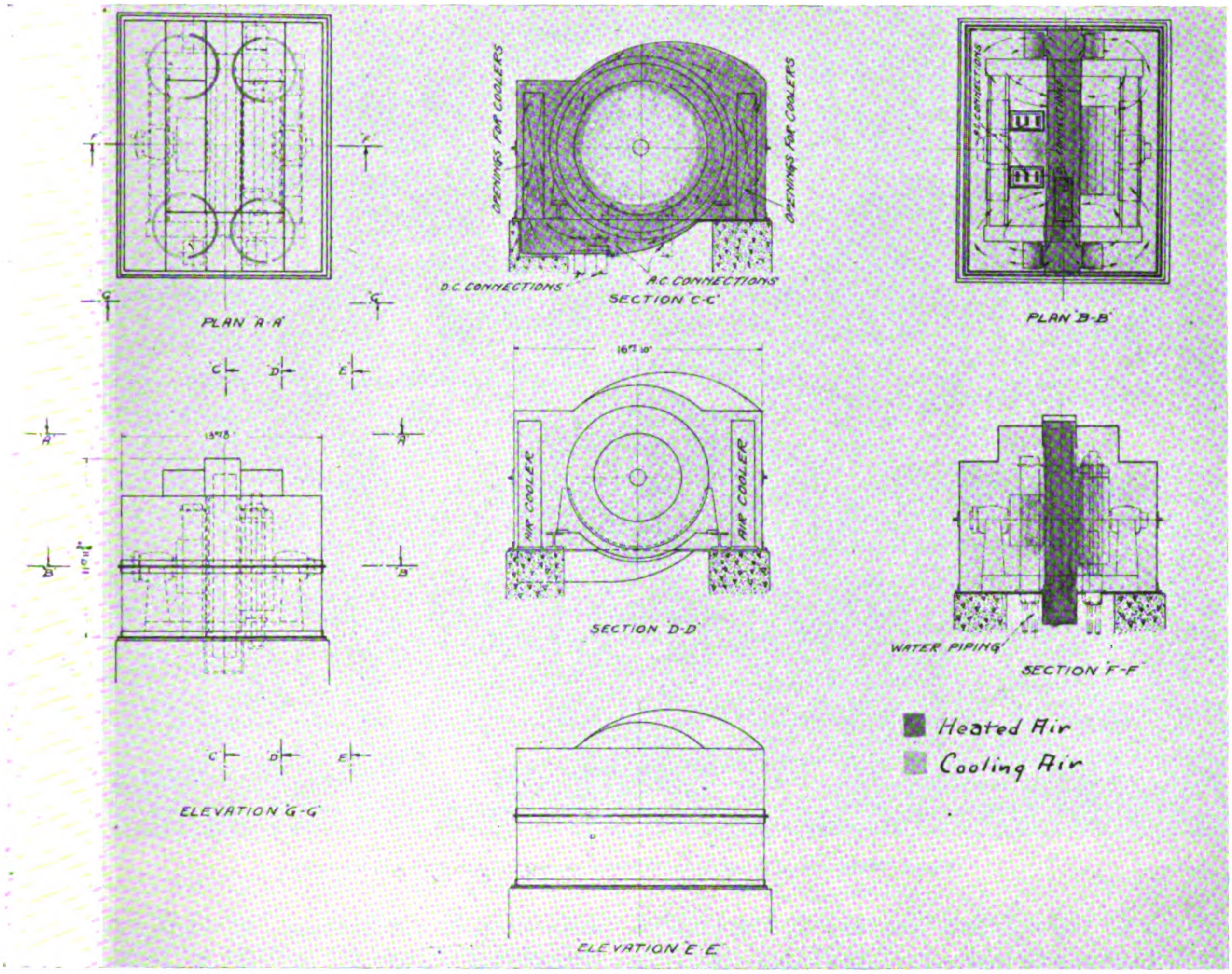

PLAN 'A-A'
OPENINGS FOR COOLERS
OPENINGS FOR COOLERS
D.C. CONNECTIONS
A.C. CONNECTIONS
SECTION 'C-C'
A.C. CONNECTIONS
D.C. CONNECTIONS
PLAN 'B-B'
16'7" 10"
13'-8"
AIR COOLER
AIR COOLER
SECTION 'D-D'
WATER PIPING
SECTION 'F-F'
■ Heated Air
■ Cooling Air
ELEVATION 'G-G'
ELEVATION 'E-E'
A
B
C
D
E
F
G

Fig. 12. Water-cooled Synchronous Converter. Plan and Elevations

General

In stations where natural ventilation by chimney action alone is resorted to for dissipation of losses it is generally conceded that openings of sufficient size to circulate air through the building at the rate of from 150–200 c.f.m. for each kw. of loss should be provided. On the basis of 1 kw. = 3415 B.t.u. per hr. this means that the average room temperature must be from 9.5–13 deg. C. higher than the outdoor temperature, being decidedly more than this at the machines and less at the intakes. Assuming further that the ventilating head is 30 ft. and inserting these values in the formula $V=\sqrt{2gh\frac{t_1-T}{273+T}}$ where V is the upward velocity in f.p.s. of the inside air due to density difference we find it to be from 550–470 f.p.m.

h = height of heated air column.

T = outdoor temperature.

t_1 = indoor temperature.

g = 32.2.

Further assuming this force to be working at 100 per cent efficiency we find that the inlet and outlet openings per kw. loss must be from 0.27–0.42 sq. ft. In actual practice this efficiency averages less than 50 per cent, corresponding to from 0.54–0.84 sq. ft. per kw. loss.

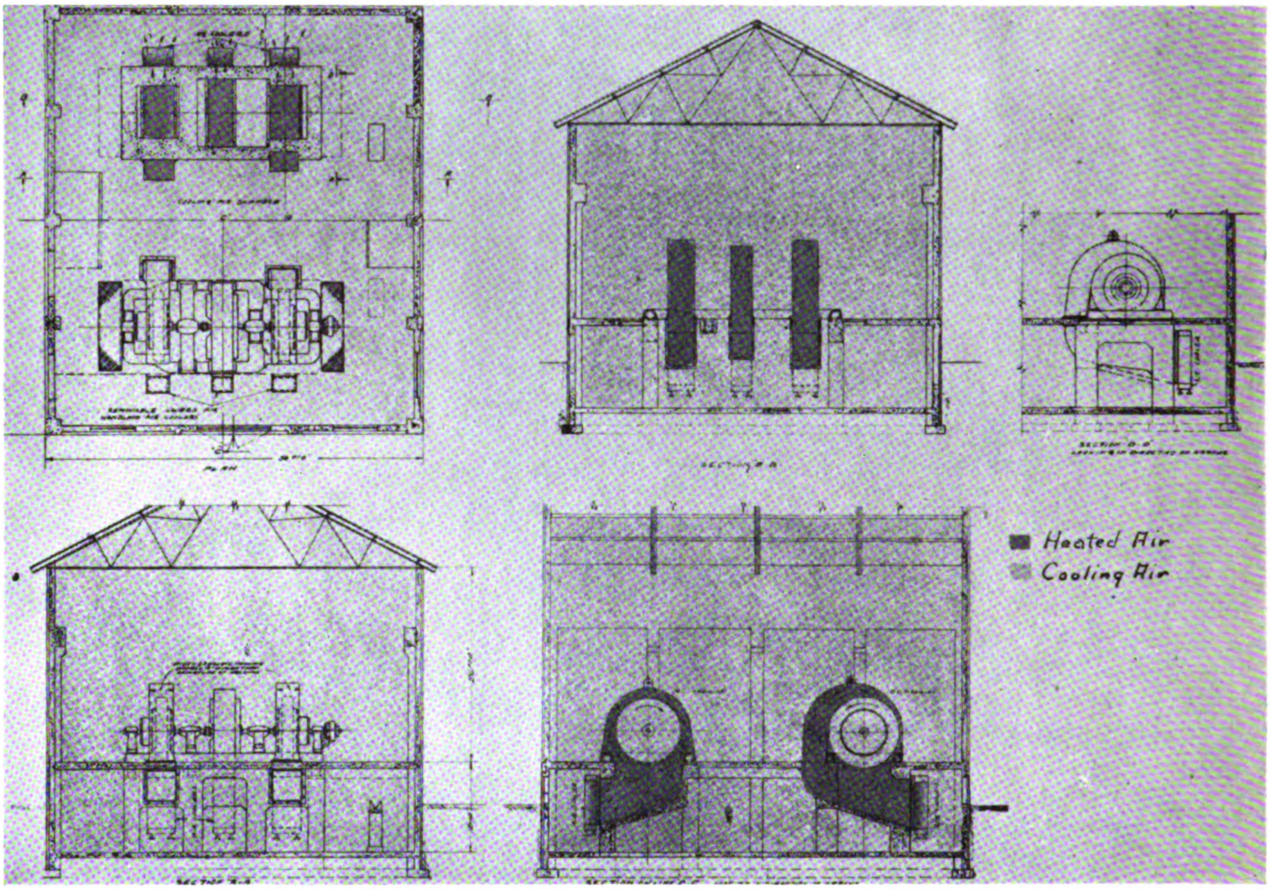


Fig. 13. Water-cooled Substation with Motor-generator Sets. Plan and Elevations

In station arrangements where proper provision has been made for separating the heated air from the incoming cooling air and conducting it outdoors a greater temperature rise of the air is permissible, since the operators need not come in contact with it except possibly at long intervals for cleaning and repairs. In practice, 100 c.f.m. of air per kw. loss has been found quite conservative. It is also possible to so conserve the energy represented by the windage losses that an air velocity of 1000–1200 f.p.m. is maintained in the housings and ducts corresponding to openings of from 0.1 to 0.084 sq. ft. per kw. loss.

Obviously such an arrangement is particularly advantageous in stations equipped with washers, filters, and blowers since the quantity of air is only from 50–67 per cent of that handled under other conditions, and the only resistance which the blowers have to overcome is that of the filters or washers.

A suggested arrangement for a-c.—d-c. motor-generator sets in which the heated air is kept separated from the cooling air and conducted outdoors is shown in Fig. 10.

WATER COOLING

In stations occasionally or permanently surrounded with contaminated atmosphere a closed system of ventilation can readily be arranged with just such housings as described, and by means of surface air coolers, which may be installed for individual machines in some such manner as indicated in Figs. 11 and 12 or for a number of machines as in Figs. 13 and 14. In the schemes shown in Figs. 11 and 12 the heated air as discharged from the machines flows through the coolers and returns directly to the machine, which in this case is completely housed. The confined quantity of air, having no communication with the exterior air, will maintain its original purity. Incidentally this construction becomes practically noise-proof. Figs. 13 and 14 show a scheme in which the heated air from several machines is discharged through surface air coolers and then released into the room from which it is again fed to the machines. Where ample water supply at low temperatures is available, it is possible to maintain lower than outdoor temperatures in warm weather with this scheme of cooling. It is not so easy to maintain the air at original purity as with the scheme shown in Figs. 11 and 12, unless airlocks be provided at the doors and window frames and the building walls are kept air-tight.

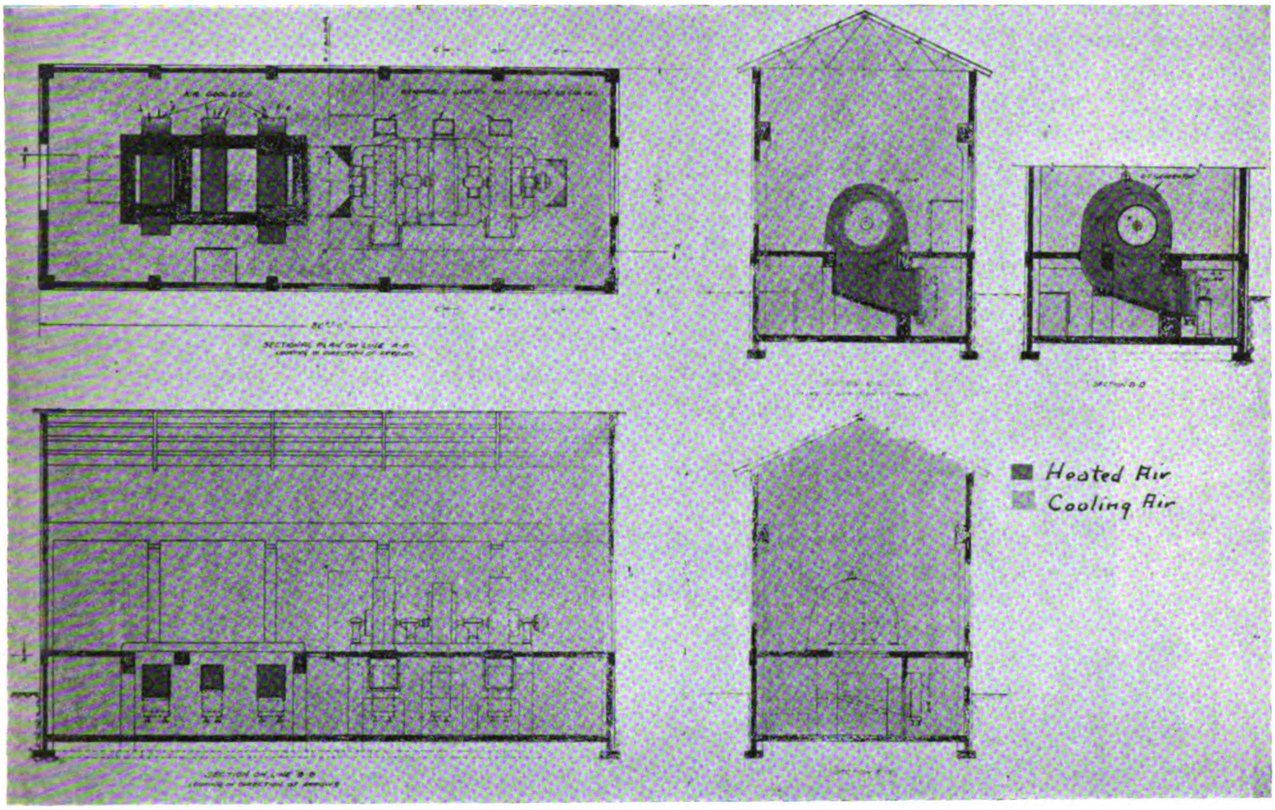


Fig. 14. Water-cooled Substation with Motor-generator Sets. Plan and Elevations

CONCLUSIONS

A method of ventilation employing means for separating the heated air as discharged from the machine and keeping it confined until it can be conducted outdoors or cooled down to its original temperature, such as here described, possesses many great advantages over the method of ventilation generally used in the past. Some of the more conspicuous advantages are:

1. Practically outdoor temperatures may be maintained in the machine room in warm weather.

2. By means of adjustable dampers, louvres, and openings in the machine housings and ducts, air circulation can be so manipulated that the machine losses can be used for heating during cold weather or for partial heating, when this is desirable.

3. Where air washers, filters, or blowers are used, they may be designed for lower capacities and lower pressures than those which would have to be employed for other types of ventilation, giving the same machine temperatures.

4. The machine will operate at lower temperatures, because the ambient air temperatures are lower than with other types of ventilation.

5. Lower first cost of installation.

6. Lower operating costs because less air is handled at lower pressures.

7. Easy adaptation to noise-proof construction.

Electric Drive Equipment for Light Automotive Vehicles

By H. S. BALDWIN
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General Electric Company

NEW demands are constantly arising and require new solutions of old problems. This is especially true of automotive work, where changes and improvements follow in quick succession. For example, during the past four years electric drive has been applied to more than 2000 gasoline motor buses operating in many of our principal cities. These require comparatively large electrical equipment as the vehicles have a seating capacity of 40 to 60 passengers or about the same as the ordinary street railway car. Buses are operated by public-utility companies over city and suburban routes, running from 100 to 200 miles daily, with frequent stops. Vehicles of this description weigh from 10 to 15 tons when loaded and require gasoline motors rated at 90 hp. or more. Under these conditions, experience has shown that electric drive has outstanding advantages that fully justify its adoption.

The system of electric drive employed consists of a generator, one or more electric motors, and electrical control apparatus instead of clutch and gear transmission such as is used in the mechanically-driven motor bus.

The principal advantages of electric drive are: facility of control in heavily congested traffic; rapid acceleration; together with quiet and safe operation. The well-known long life of electrical apparatus and its reliability are also important factors. Motor buses equipped with electric drive are always ready for service, and road trouble is seldom experienced. As might be expected, the maintenance is low. It has been found that these features appeal strongly to the riding public and operators, and statistics show that the number of electrically-driven motor buses operated by street railway companies is increasing from year to year.

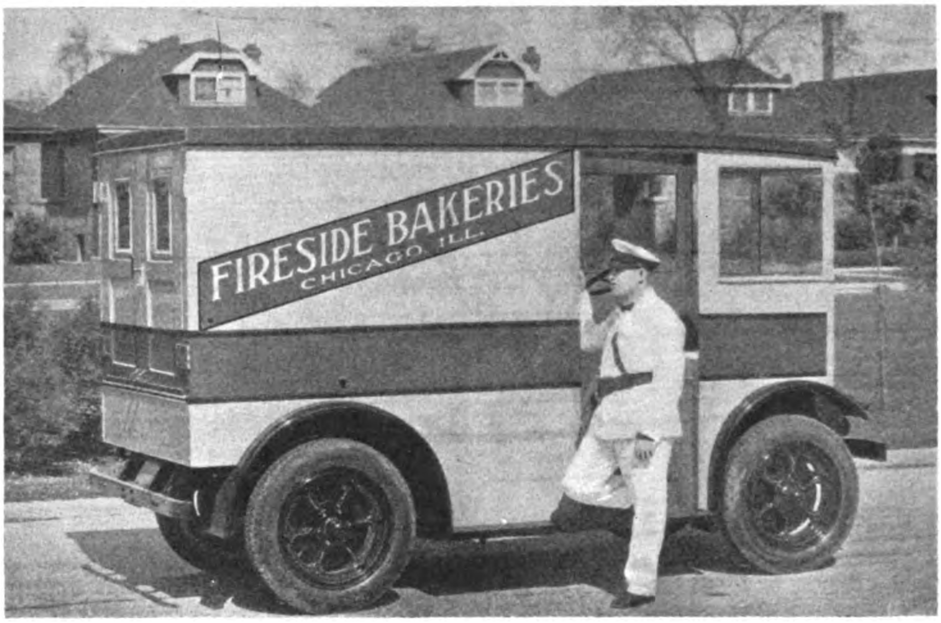

Fig. 1. Gas-electric Light Truck for Door-to-door Delivery

In the case of passenger automobiles, taxicabs, and light delivery trucks, progress in the introduction of electric drive is not so marked, because the difficulties of operation are less owing to the lighter weights moved. There are, however, special conditions in these fields for which electric drive is the logical solution of the problem, and it is the purpose of this article to give brief consideration to such an application.

Much time and effort have been devoted to the development of electric drive equipment of light weight, small size, and moderate cost. Already practical applications have been made to vehicles of each of the classes mentioned. Exhaustive road tests have demonstrated that electric drive can be produced to parallel the service performance of mechanically-driven taxicabs and light delivery trucks, but embodying the important advantages of the simple, safe, and quiet control inherent in electric drive and proved in the case of motor buses.

Modern living conditions, with dense population in cities, require daily door-to-door delivery service of not only food but many other commodities, and also make necessary various forms of special service for human comfort through the automobile. Among these, the delivery of milk is an outstanding necessity.

An interesting development in this class is the electric-drive delivery truck manufactured by the Thorne Motor Corporation, of Chicago. This will be taken as a typical case and described. Reference to Fig. 1 shows the appearance of this truck, which is especially adapted for door-to-door delivery.

A national survey places the majority of milk routes within a 40-mile travelling radius, with stops numbering from 150 to 225, which is approximately equivalent to eight and twelve stops per mile. In many cases, however, the stops are more frequent. Service of this character is clearly within the scope of electric drive and the greater the number of stops per mile the greater the advantage of electric drive over mechanical drive.

The body of the delivery truck illustrated is of the drop-center type with the platform for the operator on about the level of the sidewalk.

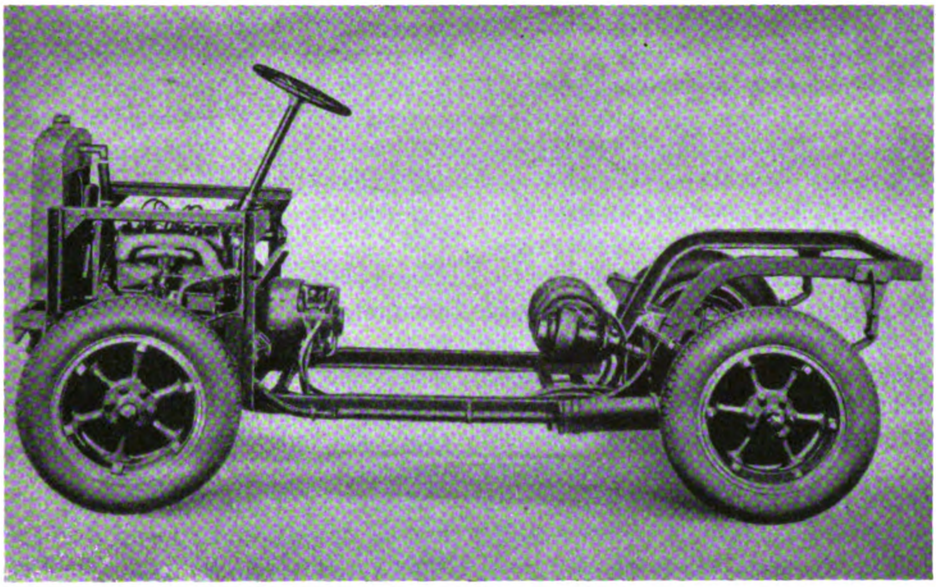

Fig. 2. Chassis of the Truck Shown in Fig. 1

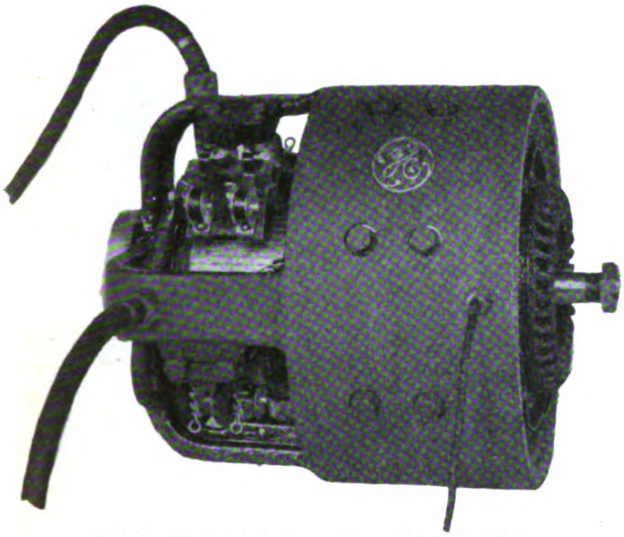

Fig. 3. The Electric Generator, which is Coupled to the Gasoline Engine

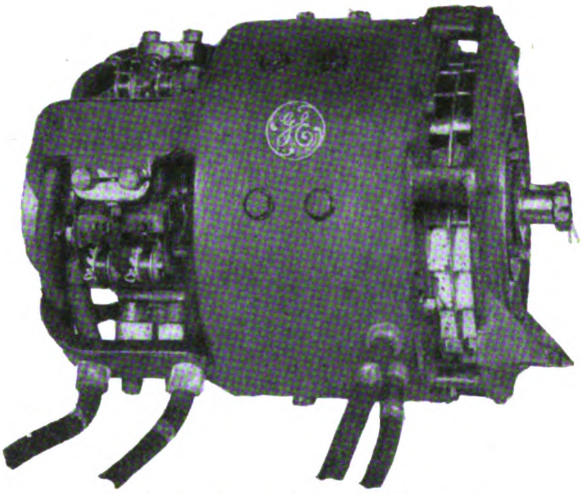

Fig. 4. The Electric Motor, which is Geared to the Rear Axle

A single power-control lever takes the place of the clutch pedal and gear-shift lever of the usual gasoline vehicle, so that in addition the driver has only to steer and apply the foot brake. This not only relieves the operator of having to make frequently repeated motions, but gives him more time to devote to the handling and care of his merchandise.

Fig. 2 illustrates the chassis and shows the location of the gasoline motor with direct-connected generator and also of the electric motor which drives the rear wheels through a spiral bevel gear having a ratio of 11.5:1.

The prime mover is a four-cylinder Continental engine of 3⅜-in. bore and 4¼-in. stroke, and S. A. E. rating of 18.22. Front and rear wheels are provided with 30 by 5-in. heavy-duty truck-type pneumatic tires which, together with special semi-elliptic springs, afford easy riding. The weight of the chassis and body complete is 4000 lb. and the carrying capacity is 3000 lb. The wheel-base is only 92 in., and the steering mechanism is arranged for turning in short radius. Experience shows that an average speed of 30 m.p.h. on level road is sufficient for milk delivery service and the power equipment and ratio of gearing are arranged accordingly.

The electrical equipment is of special design. The generator and driving motor are each rated 70 volts, 200 amp.—at 1800 and 2050 r.p.m. respectively.

Fig. 3 shows the generator, which is much the same in appearance as the motor (Fig. 4), except for the omission of the head on the driving end. Both units are of interpole design and are self-ventilated through the armatures and fields. The brush-rigging is of a special adjustable type, with double studs insulated by molded insulation material known as Mycalex. All windings and insulations are of heat-resisting felted asbestos. Mica is used wherever necessary so that the high overload capacity is assured for short periods. The continuous ratings of the machines, however, is based on 65-deg. C. rise. The generator and motor armatures are dynamically balanced and the latter are designed to operate safely at a high speed of 4000 r.p.m., which may occur at times. Heat-treated carbon steel is used for the armature shafts, and the armatures are mounted on ball bearings.

Special attention is given to the matter of banding the armature to resist high rotative speeds. The armature heads are of light section and drop forged. The series-field coils of the motor are wound of flat copper strip with asbestos insulation and the commutating-field coils are edgewise wound. The commutating poles are forged with integral lugs for supporting the coils. The field structure is fabricated from rolled plate, the joint being resistance-welded. The four arms at the commutator end of the head are electrically welded to the magnet frame and also to a drop-forged ball-bearing pocket.

While low weight and cost have been objectives, high efficiency and liberal overload capacity have been maintained.

Electricity is thus playing an ever-increasing part as the driving and control elements required by a wide variety of commercial vehicles.

The Testing of Transformers

PART IV: INSULATION TESTS, REGULATION, AND EFFICIENCY

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THE insulation of transformers should be tested (a) between windings, and also between windings and ground, by a high-potential test; and (b) between turns by an induced-voltage test.

In determining the voltage to be applied, the standardization rules of the A.I.E.E. should be followed except where the manufacturer has guaranteed that the transformers will stand greater voltage.

HIGH-POTENTIAL TEST

The high-potential test should be applied when the insulation is in its weakest condition, *i.e.*, at full-load temperature, so that the test should follow immediately after the hot-resistance measurements, except that for oil-immersed transformers a sample of the oil should first be taken for test as specified later. If the oil in the transformer has to be replaced for any reason the transformer, after refilling, should be allowed to stand one hour for each 50 kv. of the test voltage but not longer than four hours. This is done in order to drive out the possible entrapped air in the windings of the transformer.

When no heat run is made, the high-potential test should not be applied to oil-immersed transformers until they have stood for a time varying from one or two hours for medium size low-voltage transformers to five or six hours for very large high-voltage transformers.

Quality of Oil

No tests should be made with any oil that has a dielectric strength less than 22 kv. when tested between one-inch disks 0.1 in. apart. Regardless of the test voltage, a sample of the oil should be taken from the bottom of the transformer immediately before test and its dielectric strength determined.

Duration of Test

The high-potential test should be of one-minute duration unless otherwise specified.

Preparation of the Transformer

The transformer should be filled to the marked oil level. Sometimes transformers are provided with adapters between the bushing and the tank, in which case these also should be filled with oil. To make sure that the adapters are filled, it may be found necessary to see if oil will flow from the small valves at their top.

Short-circuiting the Terminals and Taps

The terminal ends and the taps of the winding under test should all be joined together and to the line terminal of the testing transformer. All other terminals and parts (including core and tank) should be well connected to ground and to the other terminal of the testing transformer.

The following exceptions are allowable:

(1) When the testing voltage is 200 kv. or less, it is not necessary to short-circuit the taps of the transformer that is under test.

(2) When testing standard lighting transformers it is only necessary to connect one end of each section of the low-voltage winding to one terminal of the testing transformer and the other winding of the transformer under test to the other terminal of the testing transformer.

Cable or Wire to be Used for Connections

All the testing cables should be of at least ¼-in. overall diameter and should be provided with suitable connections for making as good a mechanical joint with the transformer terminals as possible without forming sharp corners or points.

Small bare wire may be used, but much care should be exercised to keep the wire on the high-voltage side well away from ground.

Resistance and Reactance

No resistance should ever be placed between the testing transformer and the one under test, otherwise a voltage drop will occur over this resistance because of the flow of charging current. It is permissible, however, to use reactive coils at or near the terminals of the testing transformer.

Source of Power

A sine-wave generator should be used if available. For tests of 50 kv. or less, any 60-cycle circuit which has approximately a sine wave may be used. For higher voltage tests, a sine-wave 60-cycle generator with no other load should be used.

Control of Voltage

Method of Control

(1). Resistance.

The voltage may be regulated by means of resistance in series with the low-voltage side of the testing transformer. A fixed resistance should be connected in multiple with this low-voltage winding and so set as to allow a flow of current of at least five times the exciting current of the transformer under any condition. The purpose of this arrangement is to maintain a smooth wave-shape.

(2). Induction Regulator.

Regulation may be obtained by means of an induction regulator in the low-voltage circuit of the testing transformer. This method may be used for any test voltage.

TABLE I

SPHERE-GAP SPARK-OVER VOLTAGES

(At 25 deg. C. and 760 mm. barometric pressure)

Sinusoidal (r.m.s.) Kv.	SPARKING DISTANCE IN MILLIMETERS					
	20 mm. Spheres		62.5 mm. Spheres		125 mm. Spheres	
	One Sphere Grounded	Both Spheres Insulated	One Sphere Grounded	Both Spheres Insulated	One Sphere Grounded	Both Spheres Insusulated
10	3.85	3.85	4.1	4.1		
12	4.75	4.75				
14	5.70	5.60				
16	6.65	6.50				
18	7.65	7.50				
20	8.90	8.55	8.9	8.9		
22	10.15	9.65				
24	11.75	10.85				
26	13.55	12.05				
28	15.60	13.40				
30	18.10	14.80	14.1	14.1	14.1	14.1
40			19.6	19.5	19.5	19.5
50			25.6	25.3	25.1	25.0
60			33.3	31.8	30.9	30.7
70			45.3	39.6	37.0	36.6
80			62.3	49.1	43.6	42.8
90				61.3	50.7	49.4
100					58.9	56.3
120					79.5	71.5
140					108.2	89.1
160					148.7	111.1
180						138.9

Sinusoidal (r.m.s.) Kv.	SPARKING DISTANCE IN MILLIMETERS					
	250 mm. Spheres		500 mm. Spheres		750 mm. Spheres	
	One Sphere Grounded	Both Spheres Insulated	One Sphere Grounded	Both Spheres Insulated	One Sphere Grounded	Both Spheres Insulated
60	29.7	29.6				
70	35.3	35.1				
80	41.1	40.7	40.4	40.2		
90	47.1	46.5	45.8	45.6		
100	53.3	52.5	51.3	51.0	49.5	50.0
120	66.4	65.0	62.4	61.8	60.0	60.7
140	80.4	78.2	73.6	72.8	71.0	71.4
160	95.5	92.3	85.1	83.8	81.9	82.3
180	111.9	107.4	96.8	94.9	93.0	93.4
200	129.9	123.4	108.6	106.4	104.5	104.5
220	150.5	140.8	120.9	118.3	116.0	116.0
240	175.1	159.8	134.0	130.6	128.4	127.5
260	209.0	180.2	148.0	143.6	140.5	139.5
280	255.5	203.1	162.8	157.3	152.5	152.0
300	..	230.5	178.5	171.8	165.2	164.5
320	..	263.1	195.4	187.2	178.1	177.5
340	..	..	213.7	203.2	191.8	190.7
360	..	..	233.2	219.9	206.0	204.3
380	..	..	253.9	237.4	220.5	218.2
400	..	..	276.4	255.7	235.5	232.5
420	..	..	300.7	274.8	250.5	247.0
440	..	..	327.2	294.5	265.8	261.5
460	..	..	355.5	314.8	282.3	277.0
480	..	..	385.6	335.9	299.6	293.0
500	..	..	417.7	357.7	317.5	309.5
520					336.5	326.3
540					356.0	343.5
560					377.0	361.0
580					399.0	378.0
600					422.0	396.0
620					445.0	413.5
640					469.2	435.2
660					495.5	457.0
680					525.0	479.0
700					555.8	501.5
720					588.0	524.5
740					621.5	548.0
760					659.0	572.0
780					701.0	597.0
800					747.0	623.5
820					795.5	651.2
840						680.0
860						709.5
880						742.0
900						776.0

(3). Alternator.

Regulation may be obtained by variation of the alternator field strength. That generator connection should be used which will require approximately normal excitation. This method also may be used for any voltage.

Limits of Control

(1). Tests above 125 kv.

First adjust the sphere-gap and its series resistance to the setting for the desired testing voltage, according to the instructions given later in the sections "Use of Sphere Gap" and "Sphere-gap Sparking Distances." As stated in the later section "Application of Voltage," increase the voltage until the gap breaks and note the voltmeter reading at that instant. Break the gap in this manner three times and record the average voltmeter reading.

Then set the gap for a 20 per cent higher breakdown value and again raise the voltage, as instructed in "Application of Voltage," until the voltmeter shows the reading that was determined as the average value in the test described in the preceding paragraph. Hold this voltage for the specified length of time and then reduce it slowly to zero.

If the sphere-gap arcs over during this final test, a careful inspection should be made to discover the cause, such as loose contacts, sharp points from which a spark might pass to the tank, etc.

(2). Tests of 125 kv. and less.

Either the method described under "Tests above 125 kv." or the following may be employed:

Set the sphere-gap with resistance in series at 20 per cent above the voltage desired.

Raise the voltage, as instructed in "Application of Voltage," until the voltmeter coil in the testing transformer indicates the proper test value. Hold this reading for the specified length of time and then reduce the voltage slowly to zero.

The following exceptions are allowable:

(a). For transformers of 100 kv-a. and less to be tested at 50 kv. or less, it is permissible to depend on the ratio of the testing transformer to indicate the proper test voltage.

(b). For transformers of 100 kv-a. and less to be tested at 15 kv. or less, it is in addition permissible to omit the spark-gap.

Application of Voltage

In order to drive out entrapped air before the full test voltage is applied, all transformers which receive a high-potential test of over 100 kv. are as a general rule subjected to the so-called "bubble run," which is essentially an 80 per cent high-potential test. The voltage should be brought up to 80 per cent of the high-potential test value by the method to be described, held for one minute, and then slowly reduced to zero. The transformer should then be allowed to "rest" for at least two minutes before applying the 100 per cent high-potential test.

The high potential should be applied at one-quarter or less of the final value, and then brought up at the rate of about 100 kv. per minute. The length of time required for raising the voltage should never be less than one-half minute or more than one and one-half minutes. This will necessitate raising the voltage at a higher rate than 100 kv. per minute on some high-voltage transformers. The current should never be interrupted by fuses or switches except at the minimum voltage.

Use of Sphere-gap

Position

When a sphere-gap is used, it should be placed as near as possible to the transformer under test and certainly not more than 30 ft. away.

Series Resistance

To prevent high-frequency oscillations in the case of a discharge across the sphere-gap, and to limit resultant current, a non-inductive resistance of about one ohm per volt of the test voltage should be inserted in series with gap.

If the test is made with one terminal grounded, the entire resistance should be inserted in series with the non-grounded electrode. If neither terminal is grounded, one-half of the resistance should be inserted in series with each electrode. In either case, this resistance should be as near to the sphere-gap as possible. A water tube is the most suitable form of resistor for the purpose. Carbon rods of approximately ¾-in. diameter and approximately 8 in. long, having a resistance of not more than 4000 ohms per unit, may be used. (Carbon resistors of high specific resistance should not be employed because their resistance may become very low at high voltage.)

Sphere-gap Sparking Distances

Table I gives sparking distances between spheres for various r.m.s. values of sinusoidal voltage.

Effect of Air Density on Spark-over Voltage

The spark-over voltage, for a given gap, decreases with decreasing barometric pressure and increasing temperature. This variation may be considerable at high altitudes. When the elevation above sea-level is not great, the relative air density may be used as the correction factor. When the altitude is great, or greater accuracy is desired, the correction factor corresponding to the relative air density should be taken from Table II, in which

$$\text{Relative air density} = \frac{0.392\,b}{273 + t}$$

where

b = barometric pressure in mm.
t = temperature in deg. C.

TABLE II

AIR DENSITY CORRECTION FACTORS FOR SPHERE GAPS

Relative air density	DIAMETER OF STANDARD SPHERES IN mm.					
	20	62.5	125	250	500	750
0.50	0.573	0.547	0.535	0.527	0.519	0.517
0.55	0.617	0.594	0.583	0.575	0.567	0.565
0.60	0.661	0.640	0.630	0.623	0.615	0.613
0.65	0.705	0.686	0.677	0.670	0.663	0.661
0.70	0.748	0.732	0.724	0.718	0.711	0.709
0.75	0.791	0.777	0.771	0.766	0.759	0.757
0.80	0.833	0.821	0.816	0.812	0.807	0.805
0.85	0.875	0.866	0.862	0.859	0.855	0.854
0.90	0.917	0.910	0.908	0.906	0.904	0.903
0.95	0.959	0.956	0.955	0.954	0.952	0.951
1.00	1.000	1.000	1.000	1.000	1.000	1.000
1.05	1.041	1.044	1.045	1.046	1.048	1.049
1.10	1.082	1.090	1.092	1.094	1.096	1.097

Correction curves may be plotted for any given altitude if desired. It will be noted in Table II that for values of relative air density above 0.9 the correction factor does not differ greatly from the relative air density.

Correction of Gap Spacing for Air Density

To determine the gap spacing for a required spark-over voltage, divide the required voltage by the correction factor obtained from Table II and use the new voltage thus obtained to find the corresponding spacing from Table I, using a graph of the latter if more convenient.

Correction of Voltage for Air Density

To determine the spark-over voltage for a given gap spacing, multiply the voltage corresponding to the gap spacing obtained from Table I by the correction factor From Table II.

Test Voltages

Transformers

In determining the value of voltages to be applied, the A.I.E.E. Rules should be followed.

Autotransformers

Since the high and low-voltage windings are connected together, the total winding should be tested only at a voltage suitable for the low-voltage winding.

Permanently Grounded Transformers

Transformers with neutral or one end of a winding permanently grounded to the core require no high-potential test of that winding.

INDUCED-VOLTAGE TEST

The last test to be made on all transformers is the induced-voltage test. It is applied in order to test the insulation between turns and between sections of the winding, and to determine if the preceding high-potential test had caused any damage to the windings.

The voltage to be applied for this test ranges from two to four times normal, the specific values being given in Table III.

The source of power should have an approximately sine-wave form, and a frequency such that the exciting current of the transformer under test will not exceed about 30 per cent of the normal rated current of the excited winding. Ordinarily this limitation of the current will necessitate the use of a frequency of 120 cycles or more when testing 60-cycle units. When frequencies higher than 120 cycles are used, the severity of the test is abnormally increased, and for this reason the time of applying such frequencies must be reduced to the equivalent cycles of a 120-cycle one-minute test. According to the A.I.E.E. Rules, these equivalents are as follows:

Frequency in Cycles	Duration in Seconds
120	60
180	40
240	30
360	20
400	18

Control of Voltage

The voltage should be started at one-quarter or less of the full value and be brought up steadily to full value in not less than 15 sec. After being held for the duration of time specified in the preceding

TABLE III

INDUCED VOLTAGE TEST

Class	Type	Description	Test
1	1-phase	Kv-a. $\leqq$ 100 Voltages $\begin{cases} LV < 2500 \\ HV < 2500 \end{cases}$	4 × operating volts per turn
2	1-phase	Kv-a. $\leqq$ 100 Voltages $\begin{cases} LV < 2500 \\ 2500 < HV < 3300 \end{cases}$	3 × operating volts per turn
3	1-phase	Kv-a. $\leqq$ 100 Voltages $\begin{cases} LV < 2500 \\ 3300 < HV < 4000 \end{cases}$	2.5 × operating volts per turn
4	1-phase	When voltage $\geqq$ 66 kv. grounded, for Y Y connection	3.46 × leg voltage + 1000 from line to ground
5	1-phase	When voltage $\geqq$ 66 kv. grounded, any connection except Y Y	2.73 × leg voltage + 1000 from line to ground
6	3-phase	When voltage $\geqq$ 66 kv. grounded	3.46 × leg voltage + 1000 (between lines) 2.73 × leg voltage + 1000 (from line to ground)
7	1-phase 3-phase	All else	2 × operating volts per turn

paragraph, it should be reduced slowly (in not more than 5 sec.) to one-quarter of the maximum value or less before the circuit is opened.

Transformers which have one winding grounded for operation on a grounded-neutral system should receive special care to avoid high electrostatic stresses between the windings and ground. To eliminate such stresses in single-phase transformers that have one end of the high-voltage winding solidly grounded, a ground should be placed on the low-voltage winding during the induced-voltage test. If the maximum test voltage across the low-voltage winding exceeds 10,000 volts, this ground must be made at the middle if the winding itself or at the middle of the winding of a step-up transformer which is used to supply the voltage or which is merely connected for the purpose of furnishing the ground. If the maximum test voltage across the winding does not exceed 10,000 volts, the ground may be made on the end of the winding of the same polarity as the grounded end of the high-voltage winding.

Three-phase transformers having the neutral of the high-voltage winding solidly grounded should have a ground made on the low-voltage winding during the induced-voltage test. If the low-voltage winding is Y-connected, the neutral should be grounded. If the low-voltage winding is delta connected, the ground should be made on the neutral of the Y-connection of an intermediary step-up transformer. In the case of a delta-connected secondary having a voltage rating less than 7500 volts, it is permissible to ground one of the three corners of the delta.

If there is a third winding this also should be grounded.

The increased charging current, corresponding to the higher testing frequency, and the higher potential of the induced-voltage test may produce a large voltage rise through the increased reactance of the transformer at the higher frequency. Therefore, with sine-wave voltage impressed, and with one end of every winding grounded, the voltage induced in the high-voltage winding may be greater than that corresponding to the turn ratio. For this reason a sphere-gap should be connected across the high-voltage winding and used to limit the voltage to be held.

When another transformer is used to step up the voltage for the induced-voltage test, the step-up ratio should not be trusted. The voltage should be determined either by a sphere-gap across the high-voltage winding or by the reading of a potential transformer connected across the low-voltage winding of the transformer under test. The sphere-gap method is preferable when but one means is to be used, but whenever possible both methods should be employed. After the proper voltage has been determined by the sphere-gap, the gap should be widened to a 10 per cent higher value and left connected in the circuit as a protection against over-voltages.

INSULATION FAILURES

When a transformer fails between turns, between coils, between windings, or from a winding to other parts, in such a manner that it becomes necessary to dismantle the unit, careful examination and tests should be made to determine whether failures have occurred in other parts also.

Transformers failing in the high-potential test should be given an induced-voltage test before they are dismantled. This induced-voltage test should be made in the manner specified for the regular induced-voltage test. Three-phase transformers failing in one phase should be given a full high-potential test on the other two phases, one at a time, and both windings of the two phases not under test should be grounded. If the transformer is of shell-type construction, an induced-voltage test should also be made on each phase separately (regardless of whether it failed on high potential), with both of the other phases short-circuited.

If a three-phase shell-type transformer under high-potential test fails between turns or between coils in such a manner as to make dismantling necessary, the broken phase should be short-circuited on both the high and low-voltage windings, after which the induced-voltage test should be made on the other two phases. Single-phase voltage should be impressed on each phase separately, while the other phase is short-circuited.

REGULATION

Calculation of Regulation

According to the A.I.E.E. Rules, the regulation of a constant-potential transformer "is the difference between the no-load and the rated-load values of the secondary terminal voltage at the specified power-factor (with constant primary impressed terminal voltage), expressed in per cent of the rated-load secondary voltage, the primary voltage being adjusted to such a value that the apparatus delivers rated output at rated secondary voltage."

Regulation may be determined by loading the transformer and observing the rise in secondary voltage when the load is disconnected. This method is seldom satisfactory because of the expense of making the test, and the small difference between the no-load and full-load secondary voltages.

Much greater reliance can be placed on results calculated from separate measurements of impedance watts and voltage than on an actual measurement of regulation.

Let P = Impedance watts, as measured in the short-circuit test and corrected to 75 deg. C.
E_z = Impedance volts, as measured in the short-circuit test
I = Rated primary current
E = Rated primary voltage

$\%IR$ = Per cent effective resistance drop of the transformer, *i.e.*, per cent impedance watts, at guaranteed load, corrected to 75 deg. C.

$$\%IR = 100 \times \frac{P}{EI}$$

$\%IX$ = Per cent reactance drop between the primary and secondary windings. This is independent of temperature.

$$\%IX = 100 \times \frac{\sqrt{E_z^2 - \left(\frac{P}{I}\right)^2}}{E}$$

p = Power-factor of the load. This is always positive.

q = Reactive-factor of the load. This is positive for lagging loads; negative for leading loads. Its value is equal to $\sqrt{1-p^2}$. Some pairs of corresponding values of power-factor (p) and reactive-factor (q) are:

p	q	p	q
1.00	0.00	0.65	0.76
0.95	0.312	0.60	0.800
0.90	0.436	0.50	0.866
0.85	0.527	0.40	0.916
0.80	0.600	0.30	0.954
0.75	0.661	0.20	0.980
0.70	0.714	0.00	1.000

Then:

For unity-power-factor load

$$\text{Per cent regulation} = \%IR + \frac{(\%\, IX)^2}{200}$$

For other power-factors

Per cent regulation

$$= p \times \%IR + q \times \%IX + \frac{(p \times \%IX - q \times \%IR)^2}{200}$$

Autotransformers

For autotransformers, $\%IX$ and $\%IR$ should be calculated in the same manner as for transformers. These values should be multiplied by the co-ratio

$$\frac{\text{Rated voltage (H-v. winding)} - \text{Rated voltage (L-v. winding)}}{\text{Rated voltage (H-v. winding)}}$$

after which they should be used in the preceding formulas given for transformers.

EFFICIENCY

Calculation of Efficiency

The efficiency of a transformer is the ratio of the useful power output to the total power input.

According to the A.I.E.E. Rules, the following method of determining efficiency is recognized as standard:

Conventional Method

The efficiency is obtained from the component losses and it is the ratio of the power delivered by the machine to the power received by it. Thus

$$\text{Efficiency} = \frac{\text{Output}}{\text{Output} + \text{total losses}}$$

wherein the output and losses are both expressed in watts or kilowatts. This formula may be written:

$$\text{Eff.} = \frac{1}{1 + \frac{\%\ \text{total losses}}{100}}$$

Normal Conditions of Efficiency Determination by A.I.E.E. Standards

Voltage, Current, and Frequency: The efficiency shall be determined for the rated voltage, current, and frequency.

Temperature of Reference: The efficiency of apparatus at all loads shall be corrected to a reference temperature of 75 deg. C.

Efficiency at Fractional Loads and at a Power-factor Different from Unity

In this case efficiency can be more readily and accurately obtained from the following formula:

$$\text{Efficiency} = 1 - \frac{\%\,P_i + \%P_cF^2}{100\ pF + \%P_i + \%P_cF^2}$$

where

P_i = Core loss in per cent of the kv-a. rating
P_c = Impedance watts in per cent of the kv-a. rating
p = Power-factor
F = Fraction of load.

The usual values of F and F^2 are the following:

Kv-a. Load	F	F^2
1½	1.5	2.25
1¼	1.25	1.562
Full	1.00	1.00
¾	0.75	0.5625
½	0.5	0.25
¼	0.25	0.0625

Example

P_i = Core loss = 0.8 per cent
P_c = Impedance loss = 1.65 per cent
p = Power-factor = 0.80
F = Fraction of load = 0.75

Efficiency

$$= 1 - \frac{0.8 + 1.65 \times 0.5625}{100 \times 0.8 \times 0.75 + 0.8 + 1.65 \times 0.5625} = 0.972$$

Efficiency calculations can be considerably simplified by the use of a suitable chart, especially when calculations have to be made for several load conditions.

Fig. 27 shows such a chart arranged for direct reading for unity power-factor conditions. By expressing the losses as a percentage of the kilowatt output, the chart can be made to serve for any power-factor conditions. This is done by dividing the per cent loss at unity power-factor by the power-factor under consideration.

ACCURACY OF MEASUREMENTS

As was mentioned in the editorial note introducing this serial, the writer has attempted to describe the testing of transformers in such a manner that the work can be done with the facilities that the operating engineer is likely to have at hand.

While measurements that approach laboratory accuracy may be made in the field, such a degree of precision is seldom required in the field. Nevertheless, the conduct of a field test requires the display of considerable resourcefuless in collecting suitable testing paraphernalia and much constructive thought in its set-up, if credence is to be placed upon the results of such a test. Also, for the sake of accuracy, as well as safety, the instruments, etc., should be carefully examined before use to make sure that they are in satisfactory operating condition, for in such service they necessarily encounter more rough handling than does similar equipment in a laboratory or in a manufacturer's testing department.

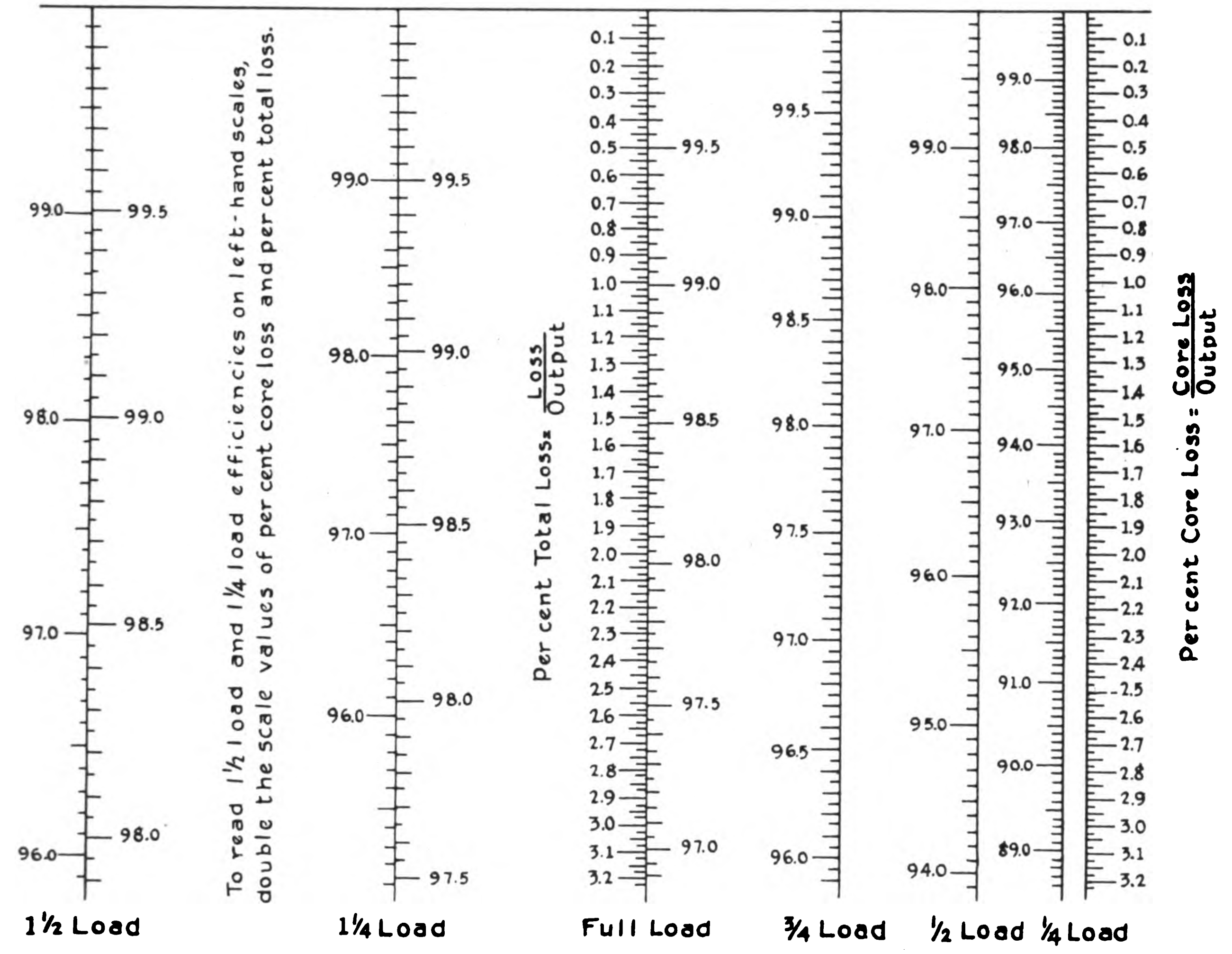

Fig. 27. Chart for Conveniently Determining the Efficiency of Transformers. A straight edge set on a given per cent core loss and per cent total loss will indicate the corresponding efficiencies for ¼, ½, ¾, 1, 1¼, and 1½ load values
Note special treatment for 1¼ and 1½ load readings.

When collecting measuring equipment that will be suitable for his purpose, the operator's testman should aim to select instruments (and instrument transformers if needed) that are of such ratings as will cause the readings to come within the central or the upper section of the instrument scales, for such readings will be more accurate than those toward the zero end of the scales.

If instrument transformers are necessary, either to act as multipliers for the instruments or to insulate them from high-potential circuits, the potential transformers should be chosen of such a ratio that their secondaries will deliver approximately 75 to 125 volts under the condition of the test and the current transformers of a ratio that will cause them to deliver about 1.5 to 5 amp. secondary. These ranges correspond to standard potential transformers having a rating of 110 volts secondary and to current transformers of 5 amp. secondary.

If the instruments and instrument transformers in such a combination are of modern design, are of a universally accepted make and undamaged, it is possible in many cases to neglect the instrument and instrument transformer corrections and still obtain results that will be reasonably accurate for the purpose of a field test. This may be due either to the errors being of negligible magnitude or to the fact that the errors of the instruments and the instrument transformers may partially neutralize each other.

However, if the assurance of greater accuracy is desired, particularly when the power-factor is in the neighborhood of 20 per cent or less, corrections should be made for scale errors in the voltmeters, ammeters, and wattmeters, phase-angle errors in the wattmeters and instrument transformers, and ratio errors in the instrument transformers. The corrections for scale errors of the instruments may readily be made if calibration curves of the instruments are available. Accounting for the remaining errors is not so simple a matter and does not fall wholly within the province of this serial. For these operations reference may be made to the books, "Instructions for Testing Electrical Apparatus," and "Instrument Transformers," which are identified by the designations GET-7 and GET-97 respectively, and published by the General Electric Company, and to the article, "Revised Tables of Phase Angle Correction Factors for use in Power Measurements," by C. T. Weller, which appeared on page 202 of the March, 1925 issue of the GENERAL ELECTRIC REVIEW.

(Concluded)

A Curious Phenomenon in Vacuum Tubes

By **W. S. ANDREWS**
General Engineering Laboratory, General Electric Company

(This hitherto unpublished article, written by Mr. Andrews in June, 1925, was recently sent to us by Mr. W. L. Lemcke of Franklin, Pa., and is here published posthumously—EDITOR)

A PLÜCKER vacuum tube was made having a stem 12 in. long with a capillary bore of about 0.008 in. (approx. 0.2 mm.). A bulb one inch in diameter at each end contained an electrode, made of aluminum wire, about one in. long by 3/32 in. in diameter, joined to a small platinum wire sealed through the glass.

This tube was first well exhausted and then filled with a half-and-half mixture of air and neon to a pressure of 10 mm. of mercury and sealed off.

When this tube is connected to an induction coil capable of giving a four- or five-inch spark, it shows the characteristic nitrogen glow throughout for about a second, then a column two to four inches long in the middle of the capillary changes to a clear red neon glow, while the two ends retain the nitrogen glow. The neon column then slowly moves toward the cathode end of the tube and disappears into the bulb only to form again in the middle part and repeat this movement indefinitely.

If the tube is excited by a high-frequency coil, the neon will segregate as before in the middle of the tube; but in this case, it wavers about without having any decided movement in either direction.

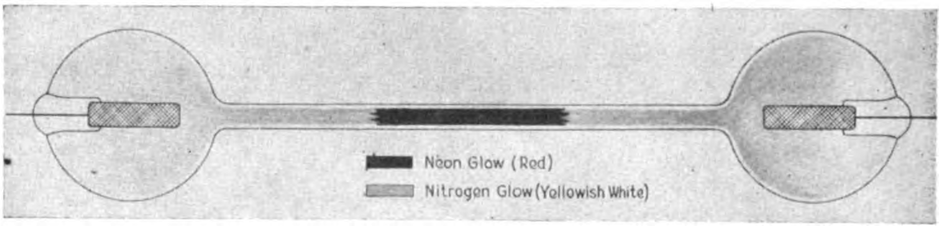

Fig. 1. Sketch of the Tube. (Not to scale)

These curious results seem to be controlled by the diameter of the bore of the capillary, for if its size is increased to 0.040 in. (about 1 mm.) all other conditions being unchanged, the nitrogen glow will prevail throughout the tube, and no separation of the two gases will take place, excepting that with the induction coil the red neon glow will appear around the cathode terminal, and with the high-frequency coil it will show around both terminals.

Industrial Electric Heating

PART XII: THE THREE-PHASE ARC FURNACE

By N. R. STANSEL
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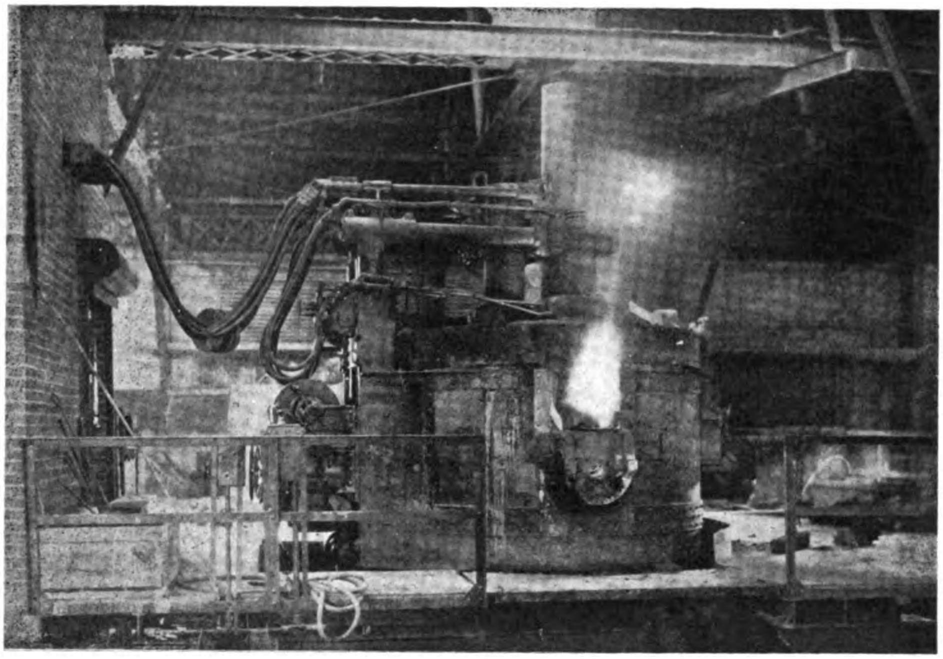
THE three-phase arc furnace is in wide use by the iron and steel industry as a method of melting in the production of steel castings and alloy steel ingots. Comparatively recently the value of the arc furnace for the production of a superior quality of cast iron has been recognized and a number of three-phase furnaces are now in use for that service.

Sizes of three-phase arc furnaces in general use for ferrous metal melting service range from 500 to 5000 kv-a. as measured by the size of the transformer which supplies power to the furnace. Typical installations of furnaces of this type are shown in Figs. 155, 156 and 157. The largest arc furnace in the steel industry today is equipped with two sets of electrodes, each set being supplied by a three-phase 10,000-kv-a. transformer.



(Courtesy of American Bridge Company)

Fig. 155. A Typical Three-phase Arc Furnace Installation

The arc furnace for use on polyphase circuits has undergone many changes in design since its introduction for melting metals. The trend in design has been toward simplicity, particularly with reference to the electrical features of the furnace. The general construction of a typical furnace as manufactured in the United States is shown in Fig. 158. Details of course vary with both the size of the furnace and the character of the service; and the designs of different manufacturers are individual. The latter is shown in the designs of the three furnace installations illustrated.

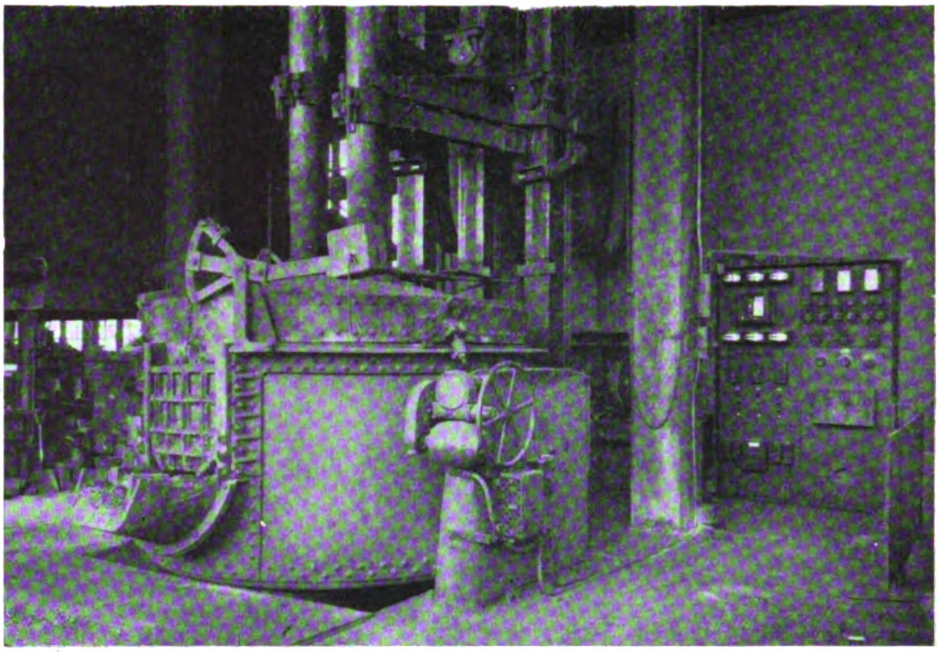
The shell of the furnace—a steel plate construction—is usually circular in cross-section, although this shape is not essential. The selection of the shape in any given case is based upon the considerations of heat storage capacity, of outside surface area (for the dissipation of heat) and of economy in construction. The hearth is a shallow bowl formed in the bottom refractory. The roof is a removable member, made as a separate part for convenience in relining and in some cases for mechanical charging. A standard practice is to provide a spare roof so that the relining of that part can be done without interrupting the service of the furnace.

The following table facilitates the location of material hitherto published in this serial:

Part	*Issue*	*Figs.*	*Equations*	*Examples*	*Tables*	*Footnotes*
Part I	Oct. 1927, p. 448	1 to 32	(1) to (8b)	1 to 3	I to III	(1) and (2)
Part II	Nov. 1927, p. 551	24 to 43	(9) and (10)	4 to 6	IV to VII	(3) to (13)
Part III	Dec. 1927, p. 600	44 to 57	(11) and (12)	8 to 11	VIII to IX	(14) and (15)
Part IV	Mar. 1928, p. 125	58 to 73	(13) and (14)	—	X to XX	(16) to (26)
Part V	Apr. 1928, p. 204	74 to 83	(15) to (21)	12 and 13	XXI to XXIII	(27) to (29)
Part VI	Sept. 1928, p. 485	84 to 99	—	14	XXIV to XXVI	(30) to (35)
Part VII	Oct. 1928, p. 560	100 to 113	(22) to (24)	15	XXVII and XXVIII	(36) to (41)
Part VIII	Dec. 1928, p. 662	114 to 138	(25)	—	—	(42) to (47)
Part IX	Mar. 1929, p. 162	139 to 144	(26) to (34b)	—	XXIX to XXXIII	(48) to (59)
Part X	May 1929, p. 278	145 to 150	(35) to (44)	—	XXXIV and XXXV	(60) to (65)
Part XI	Aug. 1929, p. 448	151 to 154	(45) to (50)	—	XXXVI to XXXVIII	(66) to (73)

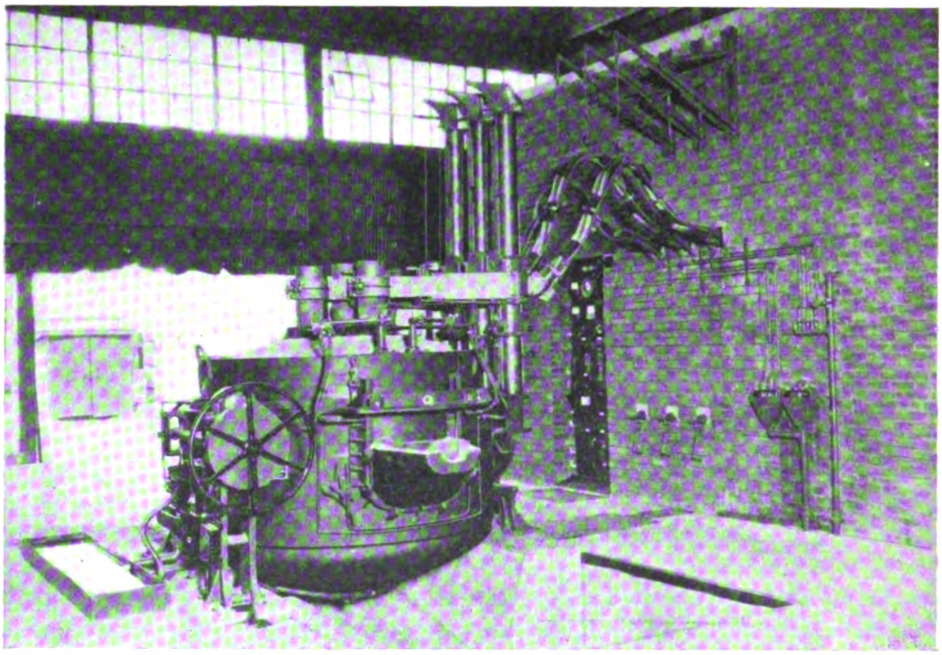
The complete electrical equipment of a furnace installation includes:

(*a*). A transformer to step down the voltage of the power supply system to the voltage or voltages needed for the furnace.



(Courtesy of William Swindell & Bros.)

Fig. 156. A Typical Three-phase Arc Furnace Installation



(Courtesy of Pittsburgh Electric Furnace Corporation)

Fig. 157. A Typical Three-phase Arc Furnace Installation

(*b*). The secondary bus structure between the transformer and the furnace.

(*c*). If the reactance of the conductors is not sufficient to obtain arc stability and to limit the current fluctuations to the desired value a reactor is added to the circuit, usually in the primary circuit of the transformer.

(*d*). Switchgear equipment for the control of the furnace, usually placed in the primary circuit.

(*e*). Instrument and meter equipment.

(*f*). A direct-current motor for each electrode.

(*g*). An automatic regulator for control of the electrode motors.

(*h*). A motor-generator set to supply direct current for the electrode motors. (Not needed if direct current is available from some other source.)

(*i*). Except for small furnaces which can be tilted by hand, a tilting motor (either a-c. or d-c.) for the operation of the tilting mechanism.

The electrical features which are characteristic of the typical three-phase arc furnace are:

(*a*). The vertical electrodes, each of which is free to move. In round furnaces the electrodes are arranged in a triangle. Rectangular furnaces may have the electrodes either placed in line or in the triangular arrangement.

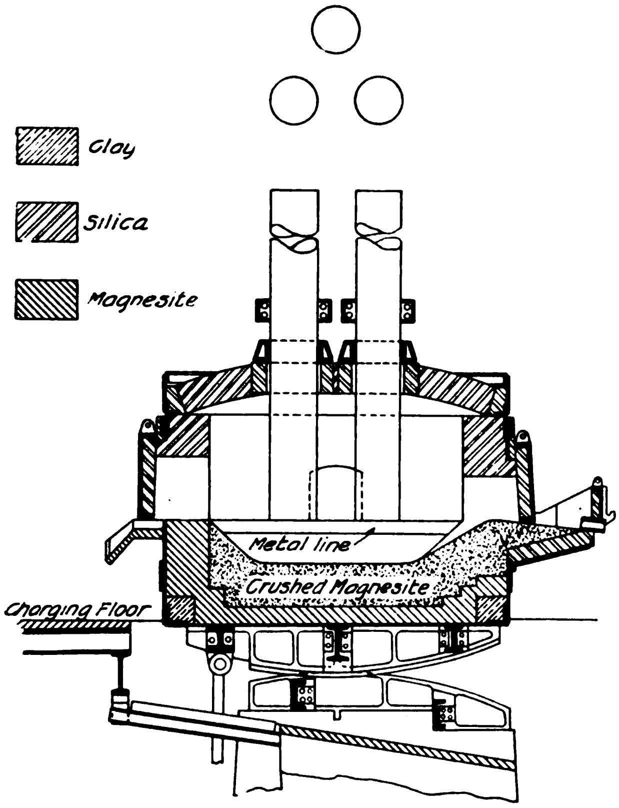


Fig. 158. Diagram Showing General Construction of a Three-phase Arc Furnace—Basic Lining

(*b*). The formation of the arcs between non-metallic (carbon) electrodes and the charge, *i.e.*, the charge forms one of the electrodes of each arc.

(*c*). The three-phase connection of the arcs is made through the body of the charge. This introduces a certain resistance in series with each arc and this resistance supplements the reactance of the circuit in maintaining arc stability.

The terms acid process and basic process(74) are fundamental terms in steel melting practice. These terms have no reference to the source of heat. The primary reference is to the chemical nature of the slag blanket carried on the surface of the molten metal during the last stage of the heat cycle.

This slag serves three purposes, *viz.*:

(*a*). A shield for the protection of the molten metal from the high temperature of the arcs; this to limit volatilization of the metal.

(*b*). As a temperature equalizer.

(*c*). In the basic process to bring about the removal of impurities from the charge by chemical action, *i.e.*, refining. (In the basic process the term melting is extended in meaning to include the refining operation.)

The lining of the hearth must be of the same chemical nature as the slag so that there may be no chemical reaction between the slag and the lining, *i.e.*, the acid process requires an acid-lined hearth and the basic process a basic-lined hearth. Silica brick is used for the acid-lined furnaces. For the basic process, the furnace hearth is lined with magnesite or with the less costly basic material, dolomite, $CaMg\ (C_3O)_2$. In both cases the side walls and roof are lined with silica brick. In some basic furnaces a layer of a neutral refractory, chrome brick, is inserted between the hearth and side walls.

The general practice in steel melting is to employ the acid process for melting steel scrap in the production of steel castings. In this case the analysis of the charge is practically the same as the desired analysis of the castings. Furnace sizes for this class of work seldom exceed three to four tons holding capacity. The basic process is used where it is necessary to refine the charge; and its general application is to the larger-scale operations in the production of alloy steel ingots. Basic-lined furnaces are needed also for the production of manganese steel castings because of the affinity of manganese for silica. As there is no refining in acid operation, that process is faster than the basic process. Hence the lower heat loss of the shorter heat cycle results in lower kilowatt-hours per ton for the acid process. As to which process is more economical in any particular case where either could be used depends upon the relative costs of raw materials and upon the cost of electric energy. Some three or four manufacturers of steel castings in the United States use the basic process.

The charge, the refractory material of the furnace structure, and the several paths of heat flow from the furnace chamber to the surrounding atmosphere must be considered jointly with reference to the flow of heat from the arcs. The heat that is developed at the lower electrodes (about one-third of the total) goes directly into the charge by conduction. The remainder of the heat from the arcs is distributed by radiation and convection—largely by radiation—in part to the charge, in part to the surrounding walls, and a part escapes to the surrounding atmosphere.

The part of the heat that is absorbed by the refractory material of the furnace enclosure, *i.e.*, the heat storage capacity of the refractory under given temperature conditions, is measured by the weight of the material and its mean specific heat. In the continuous operation of a furnace, *i.e.*, charging, melting, and pouring in sequence, the furnace structure partially cools during the period required for pouring and charging and there is a corresponding loss of stored heat for each heat cycle. Hence the temperature of the furnace when the charge is inserted is lower than the final temperature but much higher than the initial temperature of the charge. Therefore, the charge receives heat for a time from both the refractory and the arcs. The heat that is thus abstracted from the refractory is restored later as the melting proceeds and in this way the refractory material functions as a load equalizer for the power supply system.

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(74) An acid is an oxide of a non-metallic element, for example, silicon dioxide (silica), SiO_2. A base is an oxide of a metal, for example, magnesium oxide (magnesite) MgO. A neutral material is chromite, $FeO_2Cr_2O_3$, available as chrome brick. These three materials, silica, magnesite, and chrome brick, are the principal refractories used in arc-furnace construction.

The masonry construction of a typical furnace is shown in Fig. 159. This illustration also shows the relation between the volume of the refractory material and the volume of the charge when in the molten state. The weight of the refractory material in an average-size furnace is from two to three times the weight of a full charge of metal. The heat stored in the refractory when the charge is molten is about equal in quantity, as an average value, to the heat content of the molten charge. These ratios vary, of course, with the design and size of the furnace.

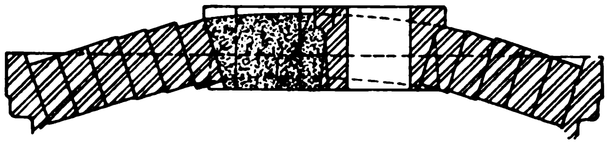
The temperature limit of the furnace is the melting point of the refractory lining, particularly that of the roof at which there is a natural concentration of heat. Pure silica melts at 1830 deg. C. Silica brick contains other constituents which lower the melting point of the brick below that of pure silica; an average value of the melting point of silica brick being 1700 deg C. The melting point of pure iron is 1530 deg. C. and that of steel some lower temperature depending upon the analysis in each case (see Fig. 119, in Part VIII). The molten charge is carried some 100 to 200 deg. C. above its melting point so that there is practically no margin between the final temperature of the charge and the melting point of the roof refractory. Hence in steel melting there is always more or less loss in the thickness of the roof refractory during each heat cycle.

TABLE XXXIX

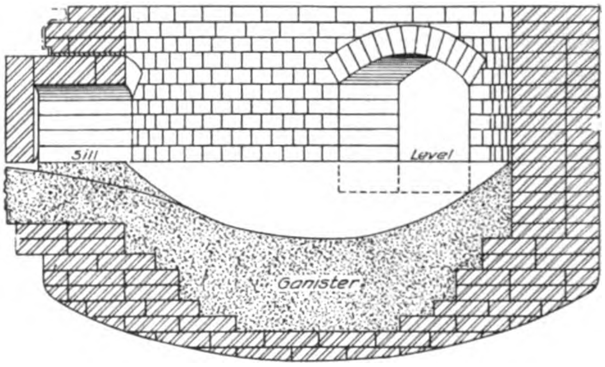
Energy Distribution for the Melting Period	Per Cent
Useful	67
Heat flow through enclosure	16
Heat flow through openings	7
Escaping gases	5
Cooling water loss	5
Total	100

A number of investigations of the heat loss from arc furnaces have been made. This loss depends upon the furnace design and size, diameter of electrodes, the extent to which water cooling is used, the roof thickness, the method of operation, and upon the mechanical condition of the furnace. Hence the wide variation in the results obtained by tests to determine this loss. Table XXXIX gives what is considered to be average results for the acid process. Similar figures for the basic process will be given later.

The heat absorption of steel at a temperature of 1575 deg. C.—from the chart in Fig. 160—is 370 kw-hr. per ton (2240 lb.). At 67 per cent conversion efficiency for the melting period we have 550 kw-hr. per ton required to bring the charge to the final temperature. If we allow 10 per cent for the electrical losses, this gives a total of 600 kw-hr. per ton. Better results than this are frequently obtained, particularly with the larger furnaces.



(*a*). Section through roof of furnace.



(*b*). Section through furnace body.

Fig. 159. Cross-sections of a Three-phase Arc Furnace, Showing Masonry Construction—Acid Lining

The average power input to a furnace required to bring a given charge to a given final temperature is obtained from three factors, *viz.*:

(*a*). The heat content of the charge at the final temperature.

(*b*). The average conversion efficiency during the time required to raise the temperature of the charge to the final value.

(*c*). The time required for the charge to reach the final temperature. In this is included the time necessary to complete the restoration of heat to the refractory, *i.e.*, at the end of this period the mean temperature of the refractory is the value which for the final temperature of the charge corresponds to the steady state of heat flow through the refractory to the surrounding atmosphere. This time period is referred to herein as the melting period. (A heat cycle is the total time required for loading, melting, and pouring.)

Thus

$$P_a = \frac{\text{Energy in kw-hr. absorbed by the charge} - \text{kw-hr. loss}}{\text{Melting period in hours}}$$

The flow of heat into the charge at any time during the melting period depends upon the temperature gradients, the areas of the surfaces of all pieces of the charge exposed to the radiation, and to the thermometric conductivity of the mass. The rate of flow of heat into the charge has the maximum value at or near the beginning of the melting period and thereafter continuously declines until temperature equalization is attained. We will designate as the normal power receptivity of a furnace containing a charge that value of power input which at any instant during the heat cycle is just equal to the rate of heat absorption of the charge plus the rate of heat loss. In this value of power input there is no surplus to be expended in melting the refractory lining. The relation between the normal power receptivity value and temperature of the charge is shown by a curve which declines slowly at first and comparatively rapidly towards the end of the melting period—as the final temperature is approached—until, when the charge has attained the final temperature desired, the normal power receptivity of the furnace is equal to the rate of heat loss at that temperature.

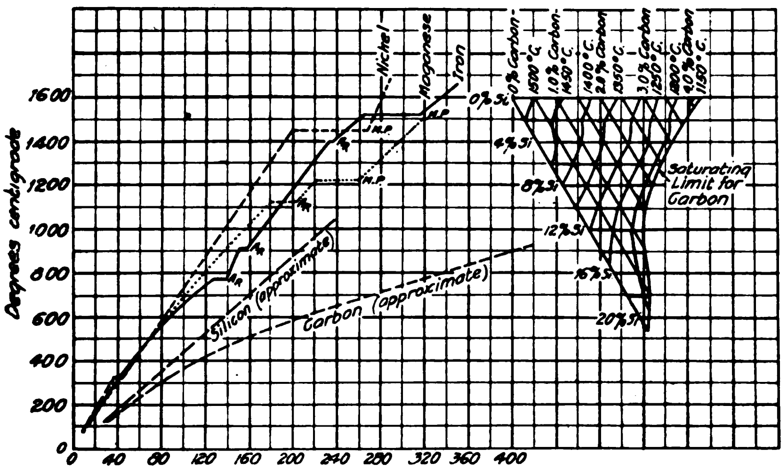


Fig. 160. Heat Content—Temperature Curves of Iron, Manganese, and Nickel

The group of curves on the left shows the heat capacities of some common materials as given by the 1920 Edition of the *Smithsonian Physical Tables*. A_R indicates a transformation; *M.P.* designates a melting point.

The Chart on the right is a melting point diagram for iron-carbon-silicon (the cast iron alloys group) as given in *Zeit. fur Anorg., Chem.*, Vol. 59. Carbon percentages are read along the 60-deg. diagonals. Heat capacities are additive. Add all fusion heats for alloys above melting point.

The time required to bring a given charge in a given furnace to the molten state and to some given higher temperature, assuming that the power available at any instant is equal to the normal power receptivity of the furnace, depends mainly upon the thermal capacity of the charge, the quantity of heat that must be restored to the refractory lining (because of heat loss from the refractory by cooling), the surface thermal resistances in the paths of heat transfer by radiation, the extent of the movement of hot gases over the surfaces of the charge, the initial physical character of the charge, the thermometric conductivities of all materials being heated, and upon the initial temperature of the charge—altogether too many variable factors to make possible the predetermination of the time element in melting practice. This time period must be assumed in calculations and the limits are the maximum time permissible from the viewpoint of the need for molten metal and the minimum time permissible by the available capacity of the power supply system or by the normal power receptivity of the furnace modified as to power input by the extent of the load-equalizing feature of the refractory. The consideration of these limits is influenced with respect to the maximum time period by the decrease in the conversion efficiency as the time allowed for melting is increased and with respect to the minimum time period by the effect of the demand charge (if any) on the cost of energy and by the investment charge against the electrical equipment.

As the load-equalizing function of the refractory lining is only partial, the initial power input to the furnace must exceed the average power input. The power-time curve of the furnace declines from the initial value and at the end of the melting period has a value equal to the rate of heat loss of the furnace. Hence this power-time curve is of the same general character as the normal power receptivity-time curve, as modified by the load-equalizing feature of the refractory lining, and more closely approaches the latter curve the larger the capacity of the electrical equipment.

The average percentage values of a number of heat balances of a 15-ton arc furnace in basic operation made by Kilnar, Reinhold and Wark(75) are shown in Table XL.

The electric energy supplied to a furnace is such a large item in the total that we can without serious error neglect the other sources of energy which go to make up the total heat input during the heat cycle.

TABLE XL

Source of Energy	Per Cent
Electric power	93.40
Charge	0.46
Reactions	2.26
Electrodes	3.88
Total	100.00
Energy Expenditures	
Steel	45.80
Slag	8.50
Electrodes	10.60
Gases	3.20
Open-door loss	3.70
Cooling water	4.80
Roof surface loss	14.20
Side surface loss	5.20
Bottom surface loss	4.00
Total	100.00

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(75) "Energy Losses of a 15-ton Heroult Furnace," *Archiv fur das Eisenhuttenwesen*, Vol. 2, p. 151.

We are not at present interested in this segregation of the energy expenditures except to note the comparatively large losses from the exposed surfaces of the electrodes and from the outer surfaces of the roof. The loss from the electrodes is a matter of the diameter, the larger the diameter the greater being the loss. (The diameter of the electrodes of the furnace referred to in Table XL was 14 inches.) The heat loss from the roof surface increases as the roof decreases in thickness, and eventually this loss reaches a value that makes it more economical to renew the roof than to continue keeping the old roof in service.

The input to an arc furnace is a fluctuating load, particularly during the melting period. Hence there is an objection, from the viewpoint of the temperature rise of the electrical apparatus, to the use of average values of power and current. However, it is not practicable to secure load charts from which to obtain r.m.s. values; and the ratio between the r.m.s. and average current values must be taken into account by conservative use of the average value of current.

An example will be used at this point, not to ascertain final values, but as it may serve to illustrate the general principles involved in the application of power to an arc furnace.

Example 16:

Charges, 10 tons (22,400 lb.) steel.

Continuous operation.

Conversion efficiency (average for the melting period), 67 per cent.

Melting time (assumed), 2 hr.

Energy required to raise the temperature of the charge to 1575 deg. C. $\frac{370 \times 10}{0.67} = 5522$ kw-hr.

Average input to furnace $= \frac{5522}{2} = 2761$ kw.

Assumed electrical efficiency at the current which gives the average power input to furnace, 90 per cent.

Assumed power-factor at the current which gives the average power input to furnace, 0.90 per cent.

Voltage of the furnace, 225 volts.

Current for the average power input to furnace, 8757 amp.

The characteristics of an arc-furnace circuit are derived, with sufficient accuracy, from the triangular relation shown in Fig. 161. In this way we obtain the chart of Fig. 162 for our assumed conditions.

Our first interest in Fig. 162 is the value of the maximum power which for a given voltage and given resistance and reactance values can be put into the furnace, and in the corresponding values of current, electrical efficiency, and power-factor. We can obtain these values quickly by the use of the following equations:

$$P' = \frac{3\,E^2}{2000\,(Z+R)} \tag{51}$$

$$I' = \frac{E}{1.41\,X}\sqrt{1-\frac{R}{Z}} \tag{52}$$

$$\tan \phi' = \frac{X}{Z+R} \tag{53}$$

$$P_t = P' + 3\,(I')^2\,R \tag{54}$$

$$\theta' = \frac{P'}{P_t} \tag{55}$$

in which

P' = Maximum power in the furnace
E = Voltage of the circuit, phase to neutral
X = reactance per phase, average
R = Resistance per phase, average
Z = Impedance per phase, average
I' = Current corresponding to P'
$\cos \phi'$ = Power-factor at current I'
P_t = Total power in circuit with current I'
θ' = Electrical efficiency at current I'.

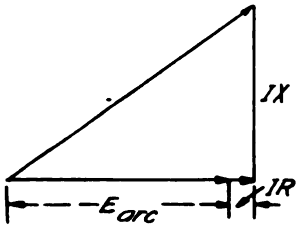


Fig. 161. Voltage Relations in an Arc Furnace Circuit

E = voltage of circuit
IX = reactance drop
IR = resistance drop
E_{arc} = arc voltage

These equations focus attention upon the importance of resistance and reactance, particularly the latter, in arc-furnace circuits as shown graphically in Fig. 162. The values P', I', θ', and $\cos \phi'$ form the criterion for the electrical operation of a furnace. Assuming that we know the resistance and reactance of the circuit, we can obtain by the use of these equations and the relation shown in Fig. 161 complete information regarding the electrical characteristics of the circuit for a given voltage.

So far furnace engineering practice has limited the voltage of arc-furnace circuits to a maximum of about 250 volts; the usual range for this voltage being from 100 to 225 volts. The main reasons for this limitation are the electrical insulation of the circuit, safety, and the restrictions which may be placed on the furnace installation by the source of power. There is the common belief that high arc voltages for steel melting furnaces tend to increase the amount of nitrogen in the steel. As only a very small amount of nitrogen in steel as poured is objectionable, this belief alone has been a factor in assigning the upper limit of the furnace voltage. However, with the growth in the average size of arc furnaces, there is of necessity a trend toward higher furnace voltages. We can go only so far in the reduction of the impedance of the furnace circuit and increasing the voltage is the only way to obtain adequate power in the furnace (through one set of electrodes) as the size of the furnace is increased.

The value of Equation (52) lies in its statement of the maximum effective current for a given case. As is shown by Fig. 162, increasing the current beyond the value I' serves only to reduce the power in the furnace. Both electrical efficiency and power-factor are affected adversely by an increase in current. The capacity of the electrical equipment is determined by temperature rise of the insulation, which is proportional to the square of the current. Hence there is nothing to gain and much to lose by the use of a current beyond the value I'.

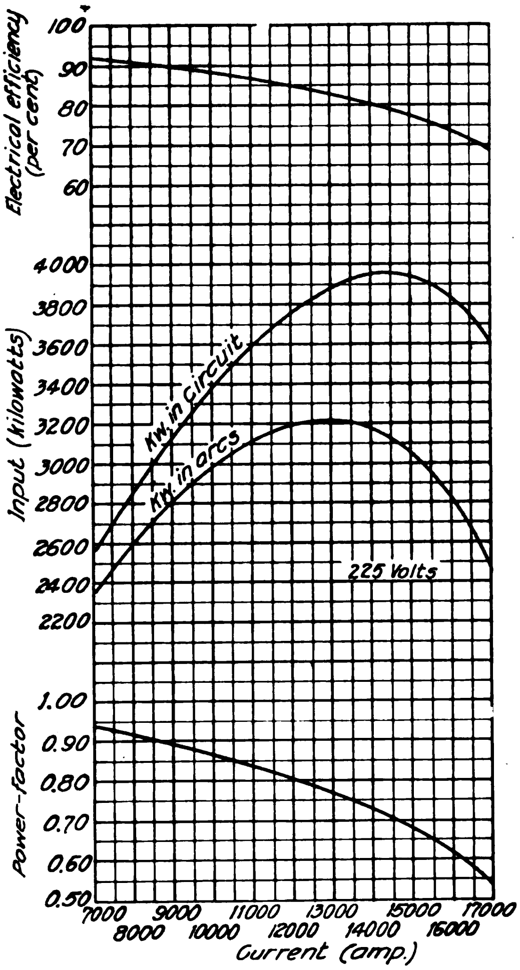


Fig. 162. Characteristic Curves of a Three-phase Arc Furnace Circuit for Given Values of Voltage, Resistance, and Reactance

As a rule it is not desirable to operate an arc furnace with the maximum power input, P', because of the consequent comparatively low values of electrical efficiency and power-factor. The extent to which the current in the arc can be reduced below the value I' depends in each case upon the particular characters of the arcs and of the charge and is a matter for determination by trial for each installation.

By reference to Fig. 162 it is noted that as the value P' is approached the gain in power input to the furnace by increasing the current becomes less and less. For example, to gain in this case the last 10 per cent in power input to the furnace requires about 30 per cent increase in current.

In practice, the power input-time curve of the furnace is followed in a more or less approximate manner by current adjustments and reduction of voltage. We seldom find a provision for more than three voltages ("high," "intermediate," and "low") and the general sequence of operations is the use of the high voltage during a considerable part of the melting period, the use of the intermediate voltage for a time followed by the application of the low voltage. Furnace operating methods vary widely. The main interest of the operator must be the product of the furnace. However, the more closely the electrical operation follows the normal heat demand of the furnace the higher is the conversion efficiency. Also as any excess power beyond the normal power receptivity of the furnace is expended in melting the refractory, the life of the refractory, particularly that of the roof, is longer the less that the power input exceeds the normal power receptivity value at any stage of the melting operation.

Before going further on the basis of our assumed melting periods of two hours it will be of interest to compare the values of P' and I' for shorter melting periods but with all other conditions the same except that we will have higher conversion efficiencies for shorter melting periods. This comparison is given in Table XLI.

TABLE XLI

Melting Period (hr.)	Conv. Eff. (per cent)	P' (kw.)	I' (amp.)
2	67	3210	12,527
1½	68	4225	16,484
1	69	6219	24,200

The flow of heat from the refractory to the charge during the first part of the melting period is fixed by the accompanying temperature conditions and is independent of the length of the melting period. Assume that from charge to charge the length of the melting period is progressively shortened by increasing the input of power to the furnace. As the length of the melting period decreases, the load-equalizing effect of the refractor becomes less and less. Thus the minimum length of the melting period in a given case is obtained when the power input-time curve coincides with the normal power receptivity-time curve of the furnace and its charge, a theoretical condition. The maximum length of the melting period is likewise indefinite, since if the power input continuously exceeds the rate of heat loss, even by a small amount, the end of the melting period will eventually be reached.

(*To be continued*)

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

Alloys, Magnetic

Silicon Steel for Transformer Sheets. J. H. Hruska.
Blast. Fur. & St. Pl., Nov., 1929; v. 17, pp. 1652-1655.
(Metallurgical qualities and methods of manufacture.)

Arc Welding

Arc Welding as an Efficiency Tool.
Soc. Ind. Engrs. Bul., Oct., 1929; v. 11, pp. 7-10.

Brazing

Copper Brazing in Electric Furnaces. H. M. Webber.
Mach., Nov., 1929; v. 36, pp. 205-207.
("Fabricating drawn and cast steel parts by copper brazing in an electric furnace with a hydrogen atmosphere.")

Coal, Pulverized

Modern Use of Pulverized Fuel in Power Stations. R. A. Chattock.
I.E.E. Jour., Oct., 1929; v. 67, pp. 1213-1227.

Corrosion

Corrosion of Metals and Its Prevention. H. E. Yerbury.
I.M.E. Proc., No. 3, 1929; pp. 545-558.

Electric Current Rectifiers, Mercury Arc, Glass-Bulb

Bulb Type Rectifiers for Charging Control Batteries. E. A. Hoxie.
Power Pl. Engng., Oct. 15, 1929; v. 33, pp. 1116-1118.

Electric Heating

Study of Electric House-Heating. A. R. Stevenson, Jr. and F. H. Faust.
Heat. & Vent., Nov., 1929; v. 26, pp. 95-98.
(From a paper before the A.S.M.E.)

Electric Lamps, Arc-Incandescent

An Epochal Light Source. M. Luckiesh.
Elec. Wld., Oct. 26, 1929; v. 94, pp. 835-836.
(Illustrated description of the new "S-1" tungsten-mercury arc health lamp developed by G-E.)

Electric Lamps, Incandescent—History

Development of the Incandescent Electric Lamp Up to 1879.
Illum. Engng. Soc. Trans., Oct., 1929; v. 24, pp. 717-746.
(Includes a bibliography, pp. 744-746, and an insert reprint of the N. Y. *Herald* article on Dec. 21, 1879, giving an account of Edison's experiments.)

Electricity—Applications—Agriculture

Electrifying 8,000 Farms. H. J. Lawson.
Elec. Wld., Nov. 2, 1929; v. 94, pp. 889-891.
(Describes a rural electrification program for the Salt River Valley district, near Phoenix, Ariz.)

Electrons

Electron Waves. C. J. Davisson.
Franklin Inst. Jour., Nov., 1929; v. 208, pp. 595-604.

Heat Insulation

Economical Thickness of Heat Insulation. R. H. Heilman.
Heat., Piping & Air Cond., Nov., 1929; v. 1, pp. 544-551.

Insulation

Insulation Faults; Their Causes and Behaviour. W. Wilson.
Wld. Power, Nov., 1929; v. 12, pp. 432-435.

Insulators

Maximum Swing of Suspension Insulators. N. L. Dolph.
Elec. Wld., Nov. 16, 1929; v. 94, pp. 980-981.
("An analytical study and recommendation to minimize flashovers and interruptions due to improper clearances.")

Lightning

Actual Lightning Measured.
Elec. Wld., Nov. 16, 1929; v. 94, pp. 978-979.
(Results of field test of lightning strokes at Wallenpaupack, Pa.)

Lightning Arresters

Unshackling the Lightning Arrester. B. E. Ellsworth.
Elec. Wld., Nov. 9, 1929; v. 94, pp. 935-936.
(Takes account of the number of right-angle turns in the lightning path across the arrester.)

Measuring Instruments

Portable Electric Harmonic Analyser. R. Thornton Coe.
I.E.E. Jour., Oct., 1929; v. 67, pp. 1249-1259.

Noises, Machinery

Why Tolerate a Noisy Operating Room? Clayton M. Allen.
Power Pl. Engng., Nov. 15, 1929; v. 33, pp. 1215-1216.
(Sound-proofing methods used in the operating room of a power plant.)

Photo-Electricity

Operating Characteristics in Photoelectric Tubes. G. F. Metcalf.
Inst. Radio Engrs. Proc., Nov., 1929; v. 17, pp. 2064-2071.

Photo-Electric Cell; A Mechanical Selective Device. Edgar H. Felix.
Am. Mach., Nov. 14, 1929; v. 71, pp. 819-821.

Power Factor

Some Technical Considerations Concerning Power Factor in Relation to Tariffs. E. W. Hill.
I.E.E. Jour., Oct., 1929; v. 67, pp. 1228-1242.

Radio Broadcasting

Wire Line Systems for National Broadcasting. A. B. Clark.
Inst. Radio Engrs. Proc., Nov., 1929; v. 17, pp. 1998-2005.

Radio Engineering—Measurements and Testing

Measurement of Frequency. Seikichi Jimbo.
Inst. Radio Engrs. Proc., Nov., 1929; v. 17, pp. 2011-2033.

Ship Propulsion, Electric

Electric Propulsion of Passenger Ships. Eskil Berg.
Shipbuilder, Nov., 1929; v. 36, pp. 787-788.
(Abstract of a paper read before the Institute of Marine Engineers.)

Statistics—Electric Railroads

Why 20 Railroads Electrified—How They Benefited.
Elec. Wld., Nov. 2, 1929; v. 94, pp. 883-886.
(Summarizes certain statistical matter recently published by the N.E.L.A. on railroad electrification in the U. S.)

Steam

Critical Relations Between Water and Steam.
Engng., Nov. 8, 1929; v. 128, pp. 595-597.
(From a lecture by Prof. H. L. Callendar before the I.M.E. Appears also in *Engineer* of the same date, pp. 487-488.)

Transformers—Parallel Operation

Parallel Operation of Transformers Whose Ratios of Transformation are Unequal. Mabel Macferran.
A.I.E.E. Jour., Nov., 1929; v. 48, pp. 809-812.
(Abridgment.)

Transformers—Temperatures and Cooling

Effect of Color of Tank on the Temperature of Self-Cooled Transformers Under Service Conditions. V. M. Montsinger and L. Wetherill.
A.I.E.E. Jour., Nov., 1929; v. 48, pp. 821-825.
(Abridgment.)

Voltage Regulators

Vacuum-Tube Voltage Regulator for Large Power Units. L. C. Verman and H. J. Reich.
Inst. Radio Engrs. Proc., Nov., 1929; v. 17, pp. 2075-2081.

X-Rays

New Wave-Length Standard for X-Rays. Arthur H. Compton.
Franklin Inst. Jour., Nov., 1929; v. 208, pp. 605-616.
(Includes a number of bibliographic footnotes.)

NEW BOOKS

(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.*)*

Creep of Steel at High Temperatures. F. H. Norton. 90 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $3.00.

Die Stromwendung Grosser Gleichstrommaschinen. Ludwig Dreyfus. 191 pp., 1929, Berlin, Julius Springer. R. M. $17.50.

(The problem of commutation is one of the oldest and most important ones in the design of direct-current machines. So far, all questions relating to this phenomenon have been interpreted by means of the classical theory of commutation which assumes a linear variation of short-circuit current with time. As is well known to every designer, however, the existence of such linear variation is questioned, and conclusions reached on this basis are sometimes erroneous. A new and more accurate theory of commutation, written by a practical engineer, will, therefore, be welcome. The author has attacked the problem with mathematical skill and thoroughness, first abandoning the assumption of linear variation. Although such a course makes the treatment somewhat complicated, the author has put his final results into a rather simple and yet sufficiently accurate form. He brings out interesting new relations between design constants and commutation. A great number of examples show how this new theory may be applied. Although considerable study will be required to grasp the contents thoroughly, the designer will no doubt be amply repaid for his efforts if the application of this new method of attack results in even a moderate improvement in the commutation of the completed machine.)

Electric Street Lighting. Charles J. Stahl. 228 pp., 1929, N. Y., John Wiley & Sons, Inc. $3.50.

("Aims to present the information most essential in the design of street-lighting installations and in the selection and use of suitable equipments for various conditions. . . This volume is not offered as a complete treatment of various phases of the subject as explored by the specialist or research worker, but deals in topics of immediate utilitarian qualities for those desiring a broad working knowledge primarily of the practical character. . . The utility of the present work will be appreciated by those who wish to make a study of street lighting, either because of the more or less constant need for information on the subject as incident to a chosen profession or for a transitory need as often encountered by city officials having for the moment a street-lighting problem to solve.")

Engineering Mechanics. Pt. 1: Simple Statics, Dynamics of Translatory Motion, Dynamics of Rotatory Motion. William S. Franklin and Zenas R. Bliss. 287 pp., 1929, Lancaster, Pa., Franklin and Charles.

(The authors feel that mechanics is the "most important fundamental course in the engineering curriculum" and that "the time ordinarily allotted to this subject is inadequate." Their solution of this problem is "to focus the attention of a class on the more fundamental aspects of the subject and to omit much that is not really fundamental." The present text has been prepared as an aid to this end. Problems and questions, with answers, are provided to illustrate the text matter. Pt. II of the work is to cover the statics and dynamics of fluids, and the statics and dynamics of elasticity.)

Forty Years With General Electric. John T. Broderick. 218 pp., 1929, Albany, Fort Orange Press. $2.50.

(Historical sketches relating to the inception and development of the General Electric Company, by one who has seen it at close quarters and over a long period of years. The author says: "The sketches contained in this book were written on my own initiative. The job of writing them was not an assignment. . . They have, therefore, had neither the benefit, nor what a pessimist might call the blight of official review or revision." Mr. Broderick's aim is to emphasize the spirit and the guiding motives of those most responsible for the initiation, growth and success of a great manufacturing concern. It is inevitable that in so doing he has found it expedient to include much that is biographical pertaining to certain outstanding characters. In particular do we find interesting reminiscences of such pioneers as Charles A. Coffin, Elihu Thomson, and E. W. Rice, Jr. The "research trio," W. R. Whitney, William D. Coolidge, and Irving Langmuir are given due consideration for their part in the important research developments of the Company. Charles P. Steinmetz is the subject of considerable biographical notice that is new despite the writings of his earlier biographers. In like manner the personalities and contributions of many others instrumental in the success of the Company are recounted. Through it all the author's endeavor has been to picture "an institution with a soul," a soul that is the product of the sound judgment and the sterling qualities of those who initiated the Company or who have subsequentey guided its policies and practices.)

Fundamentals of Electrical Engineering (Theory and Practice). William S. Franklin and Lyman M. Dawes. 512 pp., 1929, Lancaster, Pa., Franklin and Charles.

("Written as an introductory text for students of electrical engineering and as a text for non-electrical students, who, because of present-day conditions, must have a basic knowledge of electrical engineering." The purpose of the authors has been to present the elementary concepts of electrical engineering as directly as possible, without recourse to mathematical or other theory except of the simplest sort. Illustrative problems are provided. Inclusion of material on the electron theory, vacuum tubes, oscillating and coupled circuits, and the like, indicate an endeavor to bring the text abreast of present day practice.)

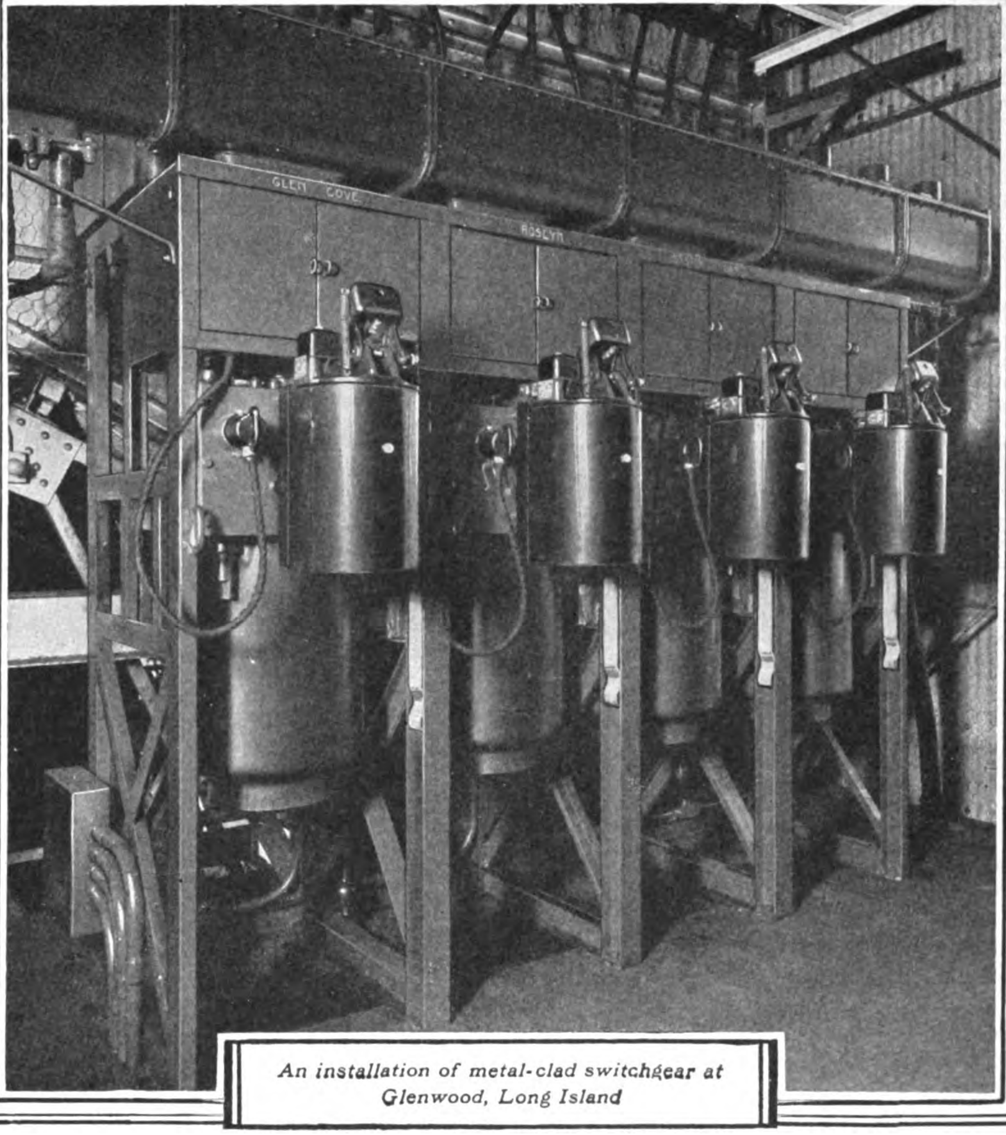
Foundrymen's Handbook. Ed. 2. 574 pp., 1929, Cleveland, Penton Pub. Co. $6.15.

Heaviside's Operational Calculus as Applied to Engineering and Physics. Ernst Julius Berg. 214 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $3.00.

(In addition to a presentation of Heaviside's operational methods, this volume contains considerable material on some of his other work and on the personality of this unique character in the world of science. Dr. Berg, who was personally acquainted with Heaviside, offers a brief personal sketch of him by way of introduction to the text proper. An appendix of considerable length, by B. A. Behrend, presents "The Work of Oliver Heaviside," an interesting account of the man as well as of his work. A bibliography of collateral reading on Heaviside methods and allied topics forms a useful adjunct to the text.)

Kabeltechnik; Die Theorie, Berechnung und Herstellung des Elektrischen Kabels. M. Klein. 486 pp., 1929, Berlin, Julius Springer.

(A German treatise on the theory, design, and manufacture of electric cable for power transmission and for communication systems. The author says that most of the earlier literature of the subject is out of date and that some of it is out of print. Hence he has attempted to present, from his fund of experience in cable manufacture, a reliable and up-to-date work for those interested in the theory, calculation, manufacture, characteristics, testing, and installation of all kinds of lead-covered cable. After his introductory chapter Dr. Klein presents a chapter on the general underlying theories involved in cable construction. Then he devotes a chapter each to the topics of theory, calculation and construction, and manufacture, of power cables, with three similar chapters applying to cables for telephone and similar work. Next follows a lengthy chapter on cable testing; then a final one on the finished cable and its utilization. The volume treats of German practice, in the main, but the practice of other countries is not entirely neglected.)



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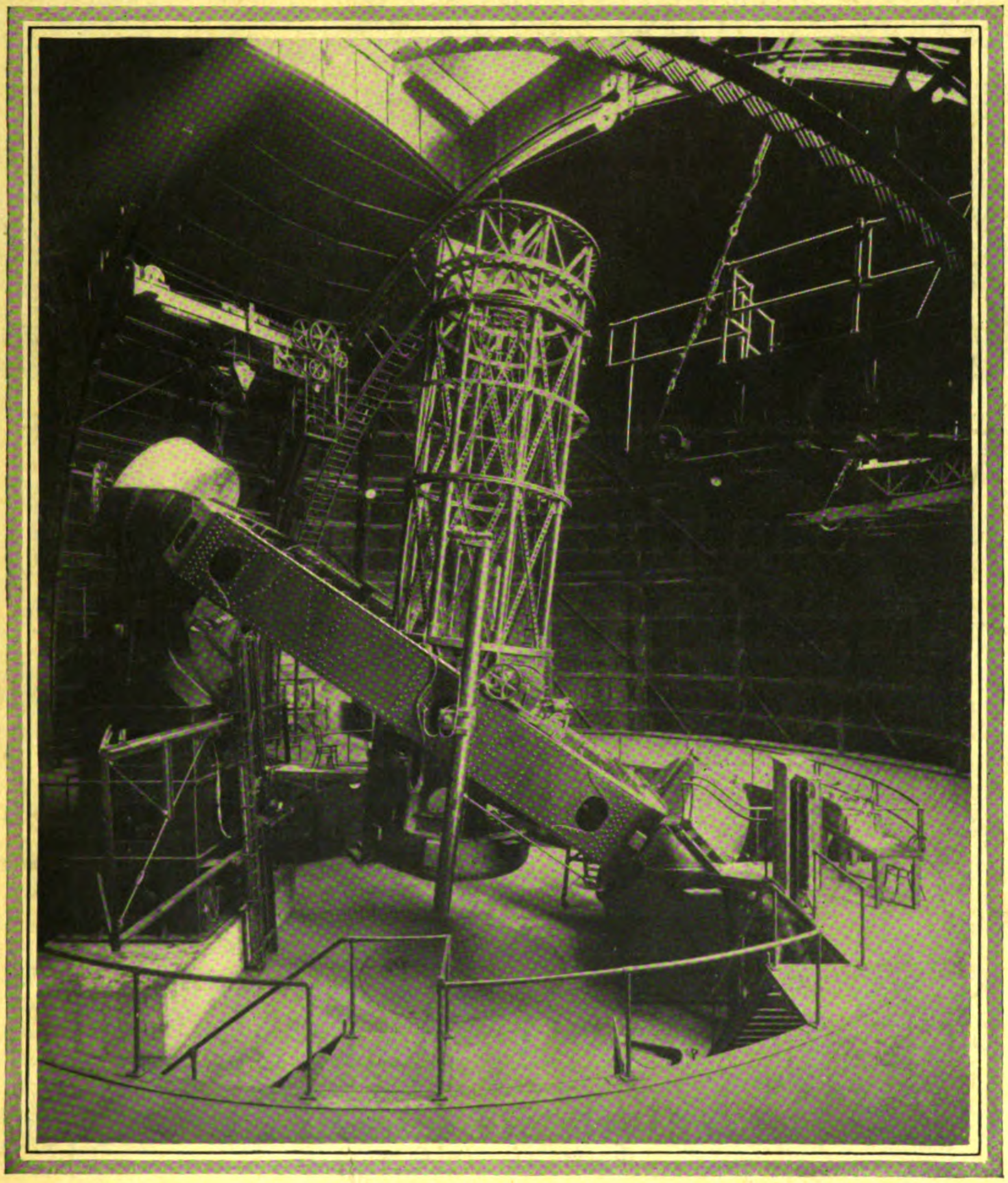
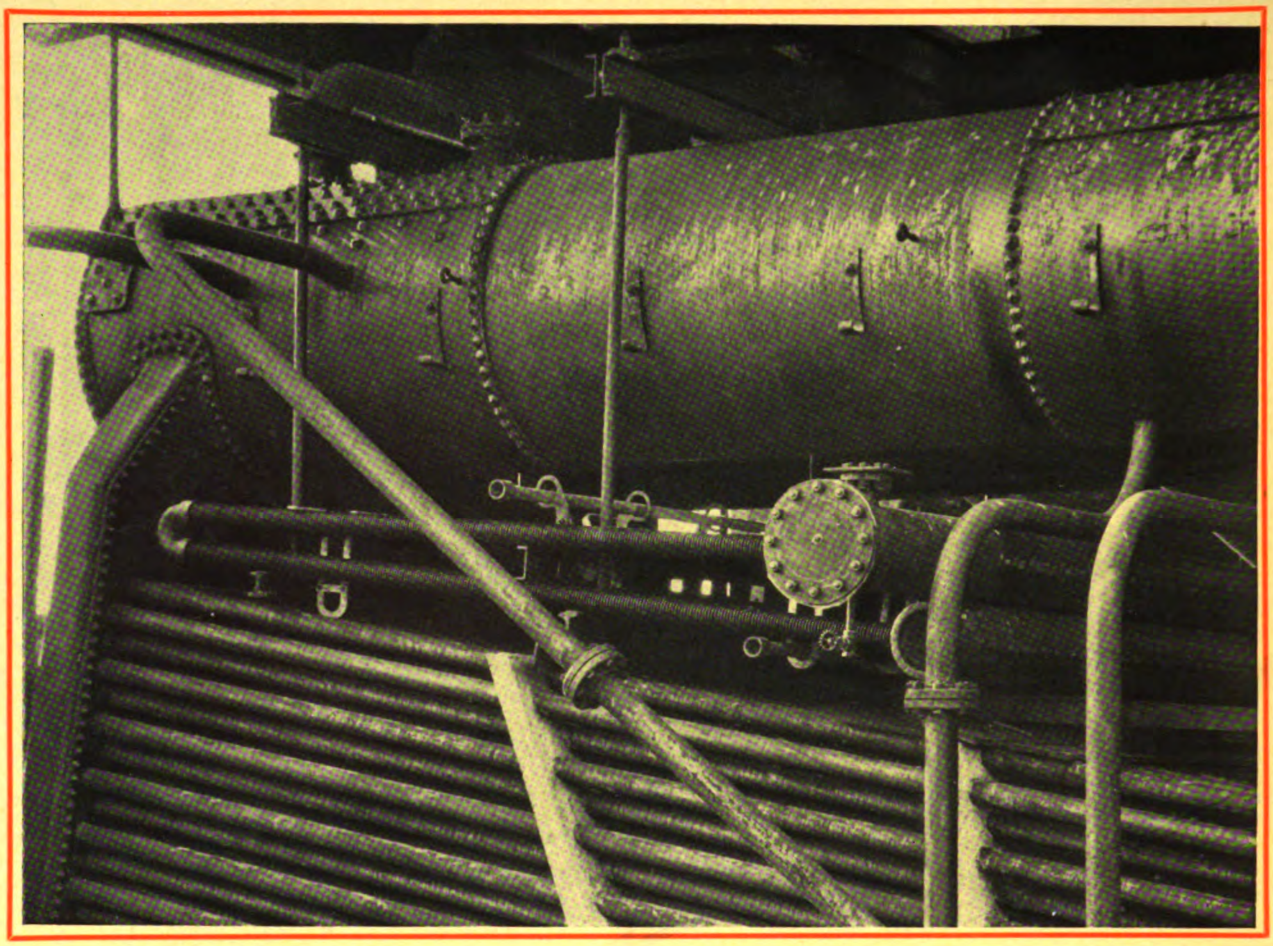


THE GREAT HOOKER TELESCOPE (100-IN.) AT MT. WILSON

Professor Elihu Thomson describes in this issue the work being done at Lynn preparatory to making a 200-in. mirror of quartz. With the building of the 200-in. telescope Science is setting out on another great and romantic voyage through the infinite realms of space to learn the secrets of the stars

In This Issue: *Heating of Outdoor Bare Conductors* *The 200-in. Telescope* *The Economics of Hydrogen Procurement* *Portable Lightning Generators* *New Multipoint Control* *Nomograms* *Lightning Investigations*



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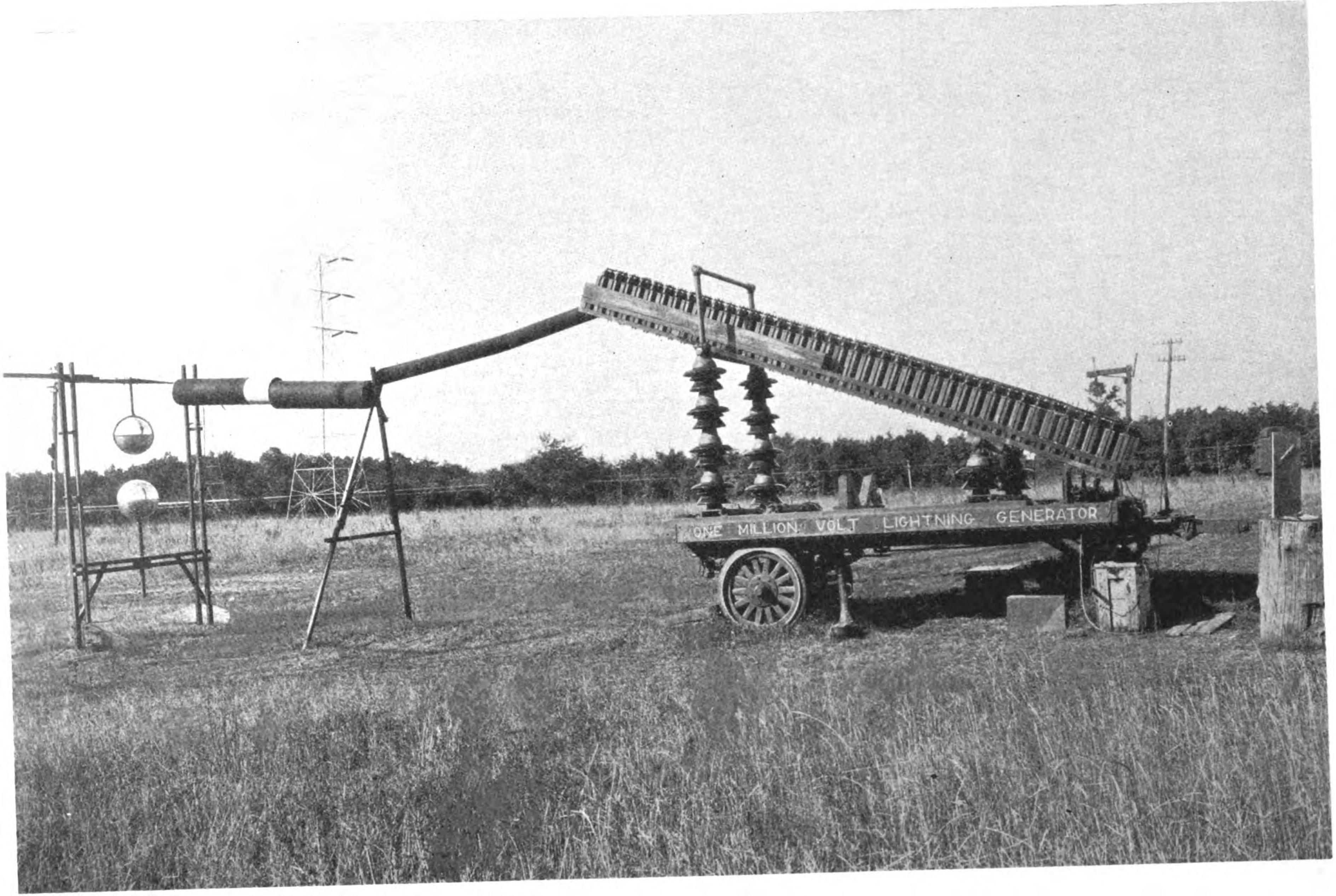
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A NEW CHARIOT FOR JUPITER

By means of such generators as this, with suitable auxiliary apparatus, a lightning impulse measured in millions of volts and millionths of seconds can be produced in the field and the instant of its discharge accurately timed. *(See p. 180)*

GENERAL ELECTRIC REVIEW

Vol. 33 **March, 1930** **No. 3**

TELESCOPES

"The heavens declare the glory of God and the firmament showeth His handiwork."

It is to gain knowledge of the everlasting heavens and in an endeavor to learn something of the Creator's laws that man is building his white-domed temples of science. In these newer temples all arbitrary dictums have been displaced by free inquiry, and truth is the only thing sought and the only authority recognized. It is in these temples that our "Watchers of the Skies" keep their nightly vigil, trying to read the secrets of the stars.

To us the heavens appear as an open book of which we have read but the first few lines, and the Music of the Spheres as the notes of that greatest orchestra from which we have heard only the first bar of its universal anthem. It is the knowledge of this ignorance that makes us thrill when we hear about the greatest of man's adventures, the making of the 200-inch telescope. In this issue we publish, in part, Professor Thomson's account of the work being done at Lynn in preparing to make the great mirror.

Man's purpose in building telescopes of ever-increasing size and power is to push back the frontiers of the universe, to extend his knowledge of our own tiny solar system, of our own universe, and to learn something of those mysteries beyond—the spiral nebulae or island universes. The purpose also is to aid the physicist, the chemist, and the geologist alike, in unraveling the secrets of Nature and to aid those many other searchers after the truth who are working in the widespread realms of many sciences. In general terms we want more powerful instruments to enlarge the utilitarian, scientific, and aesthetic blessings that astronomy holds in store for mankind.

The first telescope to be used in the service of astronomy was made by that great Italian, Galileo Galilei. His first telescope magnified three diameters. He soon succeeded in making an instrument that magnified eight diameters. He finally made a telescope that would magnify thirty-three diameters. Be it ever recorded to his credit that a magnifying power of thirty-three diameters is as large a power as could be made advantageously even today with non-achromatic lenses.

With these instruments he made discoveries that enlightened the world, confounded the philosophers, and dumfounded the church. He discovered the satellites of Jupiter, sun spots, the phases of Venus, and the hills and valleys of the moon. He proved that the pale, hazy light of the Milky Way (the equator of our universe) was caused by an unnumbered host of stars. He demonstrated the revolution of Jupiter's satellites around the planet, proved the rotation of the sun on its axis, and established the general truth of the heliocentric theory. He made clear the path that led to Newtonian geometry and to the propounding of the laws of universal gravitation.

Jeans tells us that the age of the earth is in all probability in the order of two billion years; the age of life on the earth is probably three hundred million years; the age of man on the earth is probably three hundred thousand years. The age of astronomy as a science (not including mere star gazing) is about three thousand years. The age of the telescope is three hundred years. When we bear these figures in mind it will be seen that astronomy is relatively a new thing and all but a tiny fraction of our knowledge of the heavens has been gained since that eventful night, January 7, 1610, when Galileo Galilei first turned his telescope on Jupiter.

It would be interesting to record the thrilling discoveries made with each improved telescope, but it is too long a story. However, we may add a paragraph or two, as it were in parenthesis, about two notable discoveries, of things (astronomically speaking) quite close to our own home, the earth. We refer to the discoveries of Uranus and Neptune; the one discovered with a telescope and the other by that indispensable handmaiden of all sciences—mathematics.

The interest in these is increased when we call to mind that from the remote days of the Chaldean shepherds only six of the sun's planets had been known. These were Mercury, Venus, the Earth, Mars, Jupiter, and Saturn. It was in March, 1781, that that great old musician, and indefatigable astronomer, William Herschel, pointed his seven-inch reflecting telescope, which he had made himself, to the constellation of Gemini. He beheld, not a brilliant point of light, but a shining disk of measurable size—and it did not twinkle! His trained eye and tutored mind recognized at once that he was not looking at a star. Almost a year later it was proved to be a new planet in our own family. In due time it was christened Uranus. It was ultimately determined that Uranus was 32,000 miles in diameter, and that its distance from the sun was 1,800,000,000 miles. The length of the Uranus day is still uncertain. Its year is equal to eighty-four of our years. Uranus is distinctly noticeable to a good eye on a dark night, looking something like a star of the sixth magnitude.

The discovery of Neptune, so recently as 1846, by Professor J. C. Adams, of Cambridge, and the brilliant young French astronomer, Leverrier, will ever be remembered as one of the most brilliant triumphs of the human mind. The then newest member of our family, Uranus, was not behaving as it should. It was not making its perpetual journeys around the sun in the path prescribed for it by the Newtonian geometry. Adams and Leverrier, both working independently, *by mathematics alone*, after years of labor, calculated that a planet of such and such a mass, and at such and such a distance from the sun, and in such and such a position, would account for the irregularities in Uranus' orbit. Astronomers were asked to point their telescopes to that particular point in the heavens—and behold—Neptune was there!

Neptune is the outermost member of that little family of ours we call our solar system. It is 2,800,000,000 miles from the sun and has a diameter of 34,000 miles. The length of its day is uncertain. Its year is equal to one hundred and sixty-five of our years. Neptune is invisible to the unaided eye.

Some idea of the successive increase in the power of telescopes can be gained by remembering that

Galileo Galilei's 2½-inch telescope could collect as much light as eighty-one human eyes with fully expanded iris diaphragms, and that Herschel's 18-inch telescope could collect as much light as 5,000 human eyes. A 60-inch telescope can gather as much light as 57,600 human eyes, and the famous Hooker (100-inch) telescope as much as 160,000. The 200-inch telescope will gather as much light as 640,000 human eyes combined!

Taking some data from Hale's description we learn that the 100-inch glass mirror is thirteen inches thick and weighs 4½ tons.

The new telescope is to have a mirror made of quartz, slightly larger than 200 inches (nearly 17 feet) in diameter. It will be approximately 26 inches thick and will weigh thirty tons. This mirror will be mounted at the base of a skeleton tube about 24 feet in diameter and 60 feet long. The tube and mirror will have a combined weight of 150 tons and the total weight of the moving parts will be about 500 tons. This telescope will be mounted equatorially, that is to say, the mounting will have a polar axis fixed parallel to the axis of the earth. This gigantic tube will have a range for sweeping the heavens extending beyond the North Pole and far south of the equator.

The cost of this Titan among telescopes, together with the observatory and the endowment for operation will, we believe, be about $12,000,000. A modern battleship costs about $40,000,000. How eloquent an argument for the limitation of armaments when we think of their relative value to mankind! The one for instruction, the other for destruction.

The great 200-inch telescope should be ten times as powerful as the 100-inch. It should penetrate more than three times as far into the realms of space and open up a sphere for exploration thirty times as great as that already investigated by man.

With such a volume of trackless space to explore, shall we need yet other and greater units of measurement? The astronomer started out with our earthly mile as his unit of length. Then he adopted as his astronomical unit the mean distance between the sun and the earth—92,830,000 miles. Then the light year, which equals 63,310 astronomical units or 5,880 billions of miles. And now he has adopted the parsec, equalling 206,265 astronomical units, or 19,200 billions of miles. What next?

Ten, a hundred, a thousand, a hundred thousand, a million, a billion light years are all meaningless to the average mind because of their immensity. But when the light from stars and nebulae in the outermost regions of the heavens has traveled many times these immense distances, and registered its signature on the photographic plate in our telescope, the astronomer has to turn his thoughts from the infinitely great to the infinitely small. To unravel the mysteries of a star's signature, or spectrum, the astronomer has to adopt the Ångström, which is equal to the one ten-billionth of a meter, as his unit of length. These figures give us some idea of the fineness and the greatness included in Creation's all-embracing plan.

There is a unity of the celestial and terrestrial.

The stars give us a new knowledge of the atoms and the atoms a new knowledge of the stars.

It is enthralling to contemplate what new wonders may be discovered, what old theories may be verified, or disproved, and what new theories may be propounded when the 200-inch telescope is in use.

With this magnificent instrument we may learn much about the atom with its diameter of a millionth of a millionth of an inch and we may gain knowledge of those mysterious denizens on the outermost frontiers of heaven, the spiral nebulae, whose diameters reach hundreds of thousands of millions of millions of miles.

We may learn much about the mysteries of the structure of matter and the properties of energy, which have so far escaped our physicists, from the Creator's high-temperature crucibles of the sky—the stars. These crucibles operate at temperatures exceeding many millions of degrees Centigrade and at pressures exceeding millions of tons per square inch. In the hurly-burly conditions which must exist at the center of some stars, these fabulous temperatures and inestimable pressures vie together to commit wholesale robbery of the atom's planetary electrons; and so there the elements must exist under strangely different conditions from anything we know on earth.

Matter exists in nebulae with a density at least a million times lower than anything we can attain on earth, and in the center of some stars at a density nearly a million times greater. We don't even begin to know Nature's limits.

When we have such instruments as the 200-inch telescope (or perhaps others many, many times more powerful), shall we find other planets fluttering around other suns as moths flutter around a candle? Shall we find evidence of other forms of life on other planets? Fancy looking at Venus, fancy looking at Mars, with the 200-inch telescope. Fancy surveying the hills and valleys of the moon!

Shall we be able to measure with a greater degree of certainty the diameters of Antares, Mira, and Betelgeuse, and of some of the other giants of heaven's unnumbered host? Shall we learn something about the evolution of the stars? A few years ago the evolution of the species seemed a far-fetched story; today the evolution of the stars seems a certainty.

Shall we learn something about the perplexing problems of radiant matter?

We feel very proud that the General Electric Company is playing its part in helping to produce something that should prove so useful to mankind.

We have high hopes of what we shall learn with the 200-inch telescope. But—the eternal "but"—creeps into our mind. Even after this wonderful telescope has been in use for many years, and even after yet more powerful instruments have been made and used, the dying words of that greatest of all mathematical astronomers, that famous Frenchman, Laplace, will still be true...... "What we know is but little, what we do not know is immense."

With the building of the 200-inch telescope Science is setting out on another great and romantic voyage to fly through the infinite realms of space to learn the secrets of the stars. We wish her a hearty *bon voyage*. "But"—however much we learn, Tom Taylor's lines will still be true:

> "Though ne'er so high we soar, or deep we go,
> The infinite's above us and below;
> Beyond the creeds and fancies of the hour,
> Looms, fixed and awful, A Creative Power."

J. R. H.

The 200-in. Telescope

By PROF. ELIHU THOMSON
Director of the Thomson Research Laboratory
General Electric Company, Lynn, Mass.

The following article is based on an address delivered before the Philosophical Society at Philadelphia and broadcast over a large area on December 6, 1929. Professor Thomson described the work being done preparatory to making the great 200-in. telescope—one of the most interesting tasks ever undertaken.—EDITOR

ASTRONOMERS have increased their facilities, extended their observations and have now approached the need for larger instruments in their exploration of the universe. In introducing the subject of the 200-in. telescope I will quote a paragraph from the November issue of *Harpers' Magazine*. It was from the pen of Dr. George Ellery Hale, Honorary Director of the Mount Wilson Observatory near Pasadena. He begins his text with these words:

"Astronomers, like other men, spend most of their lives in hard and often tedious routine work. They are, however, sometimes fortunate enough to take part in a great adventure, and it is of such an adventure that I am now writing."

The title of the article, of which the quotation just made is the opening paragraph, is "Building the 200-in. Telescope." I commend to anyone who is interested the reading of that article, because Dr. Hale has presented in a brief form, from the astronomers' standpoint, the reasons for, and the advantages to accrue from, building the proposed giant instrument.

It will not be my function, in dealing with the subject of the 200-in. telescope, to treat it as an astronomer would, nor shall I treat it as a designer of a huge instrument, surpassing in magnitude anything before undertaken, would treat it. I shall not compare it with a battleship in cost, although it will involve a large expenditure, but what I will have to say will concern the heart and soul of the great instrument, so to speak, namely, the mirror which reflects the light from the distant celestial objects and brings it either to the photographic plate or to the human eye.

There exists at the Mount Wilson Observatory, near Pasadena, the largest telescopic instrument in the world, usually spoken of as "The 100-inch." The mirror, which, of course, is the most important part of the instrument, is made of a great block or disk of glass, about 100 in. in diameter. It is about 13 in. thick and weighs, I think, about four or five tons. It took a long time to melt the glass; indeed, it was difficult to find any glassmaker to undertake the work, as there were so many uncertainties. Three large pots of glass were poured into a mold and cooled through months of gradual loss of heat so as to anneal the glass, and prevent its going to pieces by uneven contraction and expansion. But that was only a portion of the difficulty. Once obtained, the glass had to be worked into the form of a disk having a slightly concave surface, and this surface had to be shaped with the greatest accuracy to the form of what is known as a paraboloid of revolution, so that the light of a distant star, for example, would be brought to a single point, or as near to a point as possible. The light of a star falls on every part of the surface of the mirror, one hundred inches across, and from that face must be reflected so as to reach a focus many feet away, all parts of the extended surface coöperating to direct the light to that distant focal point. The least divergence from the proper path of the light ray from any part of the surface is destructive; the image is imperfect, blurred, more or less indistinct; the fine definition, as it is termed, is lost.

I saw the 100-in. mirror under preparation at Pasadena by Dr. George W. Ritchey. The grinding and polishing is nothing as compared with the time it takes to figure, or give final exact shape to, the mirror surface; that is, to give to it its final form within a few millionths of an inch. This is to say that the accuracy of the surface must be exceedingly great—inconceivably great for most people to visualize. When the surface is being formed by polishing it with a gently moving polisher, the glass is slightly heated and distorted. This is enough to make it necessary to stop the work for the day and put the mirror "to bed," so to speak, under five inches or more of felt covering until the next day.

The next day the first operation is to uncover it and make tests by rays of light and optical means as to its form in different parts or zones, as they are called. These tests completed, the polishing goes on with the greatest care not to overrun or spoil the work already done, until at last, after about two years of this process (with the 100-in.), the desired figure or shape is attained; be it remembered, not by grinding, not because one polishes the surface, but by polishing in just those places, and to just that extent, as will remove a very small amount of the glass and give it the paraboloidal final figure. Thus arose into being the present 100-in. mirror, the largest in the world and the basis for the largest existing telescope.

Popularly, one might imagine that the making of the mirror itself completes the work, but it does not. The mirror has then to be mounted in a balanced position so that it is not distorted by changing its position. This involves an elaborate scheme in itself. It has to be mounted so as to be turned in any direction facing the different parts of the heavens, without being bent or even slightly distorted; it has to have a very thin coat of silver deposited on its front surface, because it is not like the ordinary looking-glass mirrors; one does not look through it, but at it. The light falls on its front surface and is reflected from the exceedingly thin, polished film of silver which has been deposited on that front surface by chemical means. But that is not all, by any means; there is a great deal more. Such a mirror, however perfect be its make-up, its construction, its mounting and its silvering, is still subject to distortion whenever the temperature of the air around it changes. The face and edges of the mirror naturally change their temperature more rapidly than the body, and glass being a substance which expands by heat, the change of temperature of one part of the mirror in relation to another part by even a very few degrees practically destroys the accuracy of its reflection, and the accuracy of the images which the astronomer is seeking to examine visually or to photograph. So much so is this the case, that the temperature of the coming night must always be considered, and an effort made to guess ahead of time what that temperature may be. Means are provided for giving the mirror the assumed temperature; in many instances, of course, the assumption is incorrect.

I am told that the 100-in. glass mirror is rarely used with its full aperture or with a full opening or full face (the 100-in. circle) but its edge is often cut down more or less so as to lessen its effective size, according to the sharpness of the images.

It is difficult, indeed, to convey in a few words the necessity for exceeding accuracy of shape, or figure, of the surfaces of these mirrors and to make it understood how little a disturbance will throw them off or make them ineffective for the work for which they are designed. There are many fairly large glass mirrors in existence in the astronomical observatories of the world, but they all suffer from the same disadvantages of glass expansion which I have tried to point out, as briefly as possible.

It is now about 30 years since I made the first experiment, comparing a small slab of fused quartz, or fused silica, with a similar slab of glass, as preliminary to further work. I formed on the surface of each of these a slightly concave surface, and then used well-known optical tests to show whether the figure was maintained under different conditions. The experiment was, naturally, imperfect, but I felt sure of the result. On having the two mounted so that I could have a distinct and clear image of a small artificial star, or point of light, when used with an eye-piece as with a telescope, I found that by instantaneous application of a moderate heat or a small flame on the back of the glass slab, the image went immediately all to pieces, as we may say; that is, it scattered, all definition being lost. A similar treatment of the quartz slab showed very little change and not until the back of the quartz had become quite hot was there a semblance of the disturbance that occurred with the glass.

This experiment, modest as it was, convinced me that there was one material suitable for the making of astronomical reflectors that would avoid many of the difficulties of construction and operation inherent with the glass mirror telescopes. I have kept the matter in mind, and only in recent years have I been able to extend the work to include mirrors of such size as would be actually useful in astronomical work. Dr. George E. Hale, himself, was one of the first to ask for blocks of fused quartz from which mirrors could be made.

The task of the Thomson Research Laboratory of the General Electric Company at Lynn, of which I am Director, is simply to provide the mirror blank. This mirror body will have to include in it two new pioneer characteristics. The first is its great size; it will be far beyond anything before undertaken. It will be twice the diameter of the existing 100-in. mirror at Mount Wilson and will, therefore, have four times the surface; it will be very much thicker. It may be six to eight times the weight of the glass mirror at Mount Wilson or say 25 to 30 tons in weight. The second and more important pioneer characteristic is in the material used for such a mirror. It is not of metal, as the great Lord Ross instrument was—speculum metal, six feet in diameter; it is not to be of glass, as in the most recently constructed instruments of large size. Glass, as I have pointed out, presents great difficulties. It is very difficult to melt the glass, get it uniform and cast it, with the subsequent slow cooling and annealing through months of time; to avoid its splitting or fracturing by uneven cooling, or having within it uneven structure. It is far more difficult to shape glass to the accurate figures demanded, as the building of the 100-in. mirror showed clearly. It is even difficult to use, on account of the deformity it undergoes by changes of external temperature, disturbing the direction of the light reflected from parts of its surface, and spoiling its performance.

The 200-in. mirror is to be of fused silica, or melted quartz, melted in an electric furnace at between 1700 and 1800 deg., which means more than 3000 deg. F., or about the melting point of platinum, a metal difficult to melt, as is well known, and which does not melt in ordinary flames or furnaces. The method we shall use, and which we are using now, in fact, on a small scale with great success, is, in general terms, one devised quite a number of years ago. It consists in first melting a mass of good clean quartz sand in a circular mould in an electric furnace, and obtaining thereby a disk, or thick slab, of melted quartz sand. This is, indeed, fused quartz, but full of tiny bubbles which tend to make it lighter, but the melted sand has all the desirable properties of the solid fused quartz itself.

Now, what is the most striking and important of those desirable properties? Simply this, that it is a rigid hard material, almost expansionless by change of temperature. A bar of it a meter long, or a little over a yard long, if raised in temperature from ordinary room temperature through 1000 deg. C. or about 1800 deg. F. (a very bright heat and one which is very near the melting point of gold), expands only a half a millimeter, or about one-fiftieth of an inch. Considering this great range of 1800 deg. F., it can well be understood that under ordinary temperature changes fused quartz practically does not expand or contract. It retains its dimensions.

Now if a mirror is made of such material it retains its dimensions and does not bother the worker in either producing it or using it. There is not the long task of polishing and letting it cool between the efforts from day to day.

But I have only spoken of the foundation or base body of the mirror. I have not said anything about the second stage in its production. This comparatively rough, bubble-filled mass of melted sand, which is the underlying disk, has to be provided with a surface layer, more or less thick, of clear glass-like fused quartz, or silica glass. It will have the same general properties, so far as expansion goes, and, therefore, will suit the purpose very well united to the sand backing. The first efforts were made by melting on to the fused sand backing slabs of clear quartz made in a different way, and the results were fairly successful. Fair mirrors could be made in this way, but at the suggestion of one of our skilled workers, an experiment was made of feeding into an oxy-hydrogen blow pipe flame, granulated or finely powdered crystal quartz (rock crystal) of high quality. Immediately it was found that a coating of clear quartz could thus be deposited upon any other piece of quartz. When oxygen and hydrogen are burned together in a jet, the temperature of the flame is high enough to fuse or melt silica, or quartz. By raining down through such a flame, the granulated crystal quartz is received on a surface much as ice deposits in clear layers on objects during a sleet storm. In illustration, I often use the analogy, only adding that ours is a high temperature sleet storm, with quartz deposited in clear layers instead of ice.

Trying this with a mirror, it was found that under proper precautions of temperature, the surface might be glazed with clear fused silica to any ordinary desired thickness by the simple process of introducing high grade silica into a flame of such temperature as will melt the particles of silica readily, as they pass through it towards the surface which receives it. In this case, of course, it is the surface of the mirror to be, as composed of the fused sand backing, which, in the way I have outlined, is covered with a layer of beautiful, clear, transparent fused quartz. When I speak of fused quartz, or fused silica, or silica glass, the same material is meant and the terms are used interchangeably.

It has taken considerable effort and time, and some money, to arrive at this stage in the operation, but the results are justifying themselves right along, and were it not so I should not have been ready or willing to tell you of the progress towards the making of the 200-in. mirror. We now feel that our task is indeed an enlargement of the scale of our operations. We do not, however, minimize the obstacles which will have to be overcome in enlarging it to the great scale on which we must work when producing the 200-in. mirror. It is a gigantic thing in itself, but such a gift to science is a prize that is worth working for.

It has, of course, been necessary in doing this work—and the necessity will continue to the end of the accomplishment—that competent, enthusiastic coadjutors shall take care of the very varied things which present themselves. They must, indeed, be both competent and enthusiastic. The work has just begun, and mirror blanks suitable for use in astronomical telescopes up to about two feet in diameter are produced and producible. These have all the desirable qualities, which, of course, will be those of the great mirror. We cannot speak of taking only months to produce the large mirror; we must speak of years. It may be two or three years before the large mirror is turned out, but every product of our work is itself an acquisition for astronomy, whether it be a two-foot, three-foot, five-foot, or six-foot mirror; we must go to our goal by steps. Every one of these interim products will be a useful and desirable thing for the astronomer; in fact, the construction of the 200-in. mirror involves the production of at least two or three others of less size to be used with it, in several combinations.

The process of actually shaping, and the grinding, polishing, and figuring of these quartz mirrors, is practically the same as has been used in the making of the glass mirrors hitherto, and will be done probably at Pasadena under the care of the Mount Wilson Observatory optical staff, but with the great advantage that the work does not have to stop for equalization of temperature in the mass of the mirror as with glass. It can go on steadily, uninterruptedly, occupying days instead of years, and experience shows us that the material lends itself more readily than glass to the work of the optician.

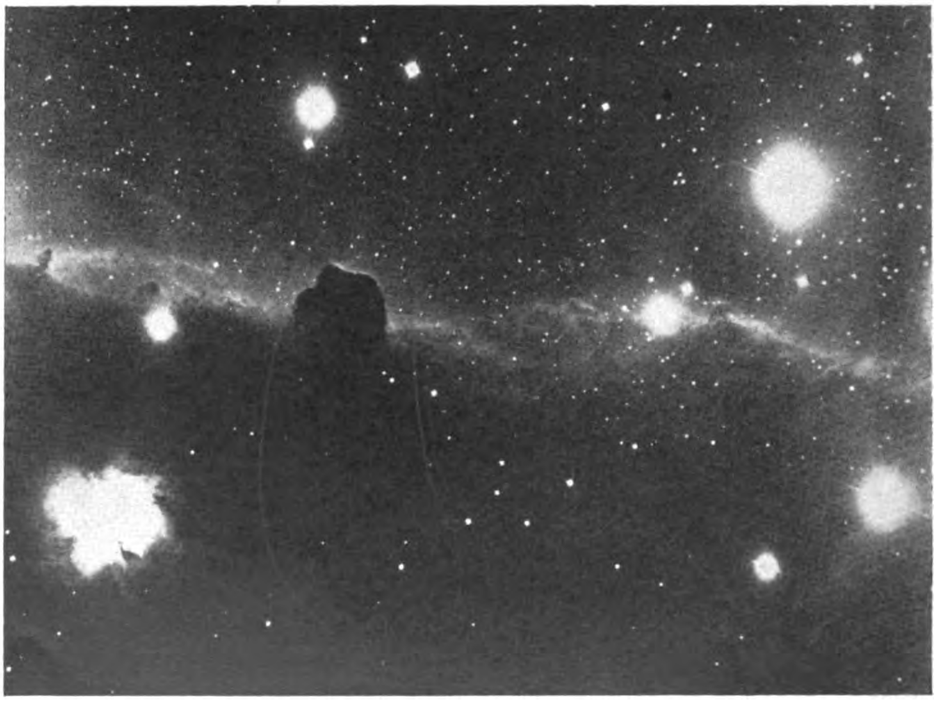
The mounting and use of the great mirror will be the same, except for a great enlargement of scale, as it would be with a glass mirror, but there will not be the disadvantage of changes of temperature disturbing the accuracy of the work or its possibility. The fearsome process of using the sun itself as the object of investigation, for example, will not trouble with a mirror of fused quartz, as it would with a glass mirror. It is, of course, necessary to establish such an instrument in the best or steadiest air that can be found, little subject to currents of different temperature which disturb the passage of the light to and from the mirror in the atmosphere itself. Proper sites are even now being sought for the mounting of the great instrument which is contemplated.

The mirror blank itself will probably be made at the River Works of the General Electric Company at West Lynn, or nearby, and I wish to mention here the fact that the undertaking is carried on at the works of the General Electric Company without any idea of profit, but merely at the cost of labor and material, and a free gift is made by that company to the enterprise, of the engineering skill and existing laboratory equipment useful to the attainment of the end in view.

Naturally, the placing of the giant instrument is a problem in itself which we can leave to the astronomers. We can leave, also, to the astronomers what may be expected from the use of the giant mirror in the completed telescope, a great engineering structure itself, except to say in general that its light-gathering power will probably be not less than four times that of the 100-in. but on account of the greater convenience this factor will undoubtedly be increased, as it can probably, in good air, be used without diaphragming down. Four times more light, with equal accuracy means that the distance of reach of exploration is increased twice, which means that our visible universe is thus increased 2 by 2 by 2, or the cube, or 8 times. If the effective light-gathering power be in still greater proportion, as is probable, then we have the universe further increased, but this, of course, is not alone the meaning or object of the instrument.

Every problem which is present with the astronomer today will, with the superb instrument, be more easily reckoned with. Its greater capacity for gathering light makes it easier to use higher magnifications if the image is accurate. It may, therefore, lead to our more complete knowledge of the planets which belong to our own system and assist greatly in the investigation of other heavenly objects which appear in our sky. It may help to solve some of the problems connected with that most interesting neighbor planet of ours, the planet Mars, about which we can form hypotheses but with little chance, thus far, of confirming or denying their validity. The major advantage may be summed up in the terms "greater and more accurate space penetration."

I cannot close this statement without paying a tribute to our laboratory staff, who so far have borne "the burden and the heat of the day," so to speak, in the development which has so far progressed. At the head of this staff is Mr. A. L. Ellis, assistant director of the laboratory, who has been most indefatigable in carrying on the development. They have all done their part, and have done it most enthusiastically and productively. I should like to enumerate them and credit to them their different contributions.



One of the Mysteries of the Heavens. The "Horse's Head," in the Great Nebula in Orion. Taken with the 100-in. Telescope at Mount Wilson

Heating and Current-carrying Capacity of Bare Conductors for Outdoor Service

Theoretical Considerations of Heating—Effects of Conditions of Exposure—Heating Tests—Comparison of Calculations and Tests—Typical Computations of Current—Summary of Conclusions

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IT is the purpose of this article to review the existing data, and to report new data, on the temperature rise of bare conductors under continuous loads in both outdoor and indoor locations, and to present formulas for the calculation of the currents to be carried by conductors limited to a given temperature rise. Moreover, the current ratings of copper conductors ranging in size from 0.3-in. diameter to 4.5-in. diameter, for a temperature rise of 30 deg. C., are tabulated for specified outdoor conditions and compared with the corresponding indoor ratings.

This article does not deal with the numerous other factors which often enter into the determination of the current to be carried by conductors, *viz.*, power loss, voltage drop, short-circuit heating, intermittent loading, annealing temperature, etc., but deals with current ratings only in so far as they are determined by the temperature rise under continuous loads.

In the literature of the subject, the current-carrying capacities recommended for outdoor service by different authors vary widely, ranging from the same values as given for indoor service to values nearly double those for indoor service intended to be applicable to the same conditions. A number of current *vs.* temperature-rise tests were therefore made with typical conductors in outdoor as well as indoor setups and the results of the tests were checked by theoretical calculations based on earlier researches. In the outdoor tests the effects of wind, sunshine, height above the ground, and sheltering effect of buildings were investigated so that these factors could be allowed for in establishing the current ratings.

This article includes the following:

A brief review of the theory of heating under continuous loads, formulas being given for the conditions of still air and of moving air (winds, drafts, etc.).

A treatment of factors such as air velocity and sunshine and of special factors such as small enclosures, warmer or cooler connections, etc., that affect conductor heating indoors or outdoors.

Data on and analysis of the prevailing wind velocities and the sheltering effect of buildings, and the determination of the wind velocity to be used for rating outdoor conductors in partly sheltered locations.

Description and results of heating tests, in tables and curves.

The effects of wind and sun.

Tabulated current ratings for 30 deg. C. rise for common sizes of wires and cables, ranging from No. 0 A.W.G. to 1,000,000 circular mils, and for tubular conductors of nominal pipe sizes ranging from ½ in. to 4 in. for outdoor service as well as for indoor service.

Numerical examples illustrating the application of the data for the calculation of the current to be carried by conductors to give 30 deg. C. rise, and instructions for the calculation of the current to give other values of temperature rise; also an example of the calculation of the temperature rise due to a given current.

The value of 30 deg. C. for the temperature rise was chosen because it is commonly used for the conductors in outdoor substations. Among the considerations which have led to the use of this rise for buses and connecting leads are the temperature limits of the insulation of connected apparatus and the deterioration of contact surfaces such as those in disconnecting switches, the deterioration being more rapid at higher temperatures.

THEORY OF CONTINUOUS HEATING

A brief review of the theory of heating as applied to bare conductors in air is given for the purpose of showing the effect of factors such as conductor diameter, absolute temperature, and air velocity upon the temperature rise. For a complete discussion of the theory involved reference may be made to papers by C. W. Rice(1) in which general formulas are given. The theoretical formulas given below have been adapted from these general formulas. In the application of the general theory to the case of the conductors covered in this investigation, valuable assistance was given by W. J. King.

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(1) "Free and Forced Convection of Heat in Gases and Liquids," by C. W. Rice, *A.I.E.E. Trans.*, Vol. 42 (1923), p. 653, and "Free Convection of Heat in Gases and Liquids," by C. W. Rice, *A.I.E.E. Trans.*, Vol. 43 (1924), page 131.

The following symbols are used:

A (sq. in.)	Area of surface of conductor.
a, a_1 (cir. mils)	Area of cross-section of conductor.
C	Factor in formulas for current-carrying capacity, defined by Equation (11).
d (in.)	Outside diameter of conductor.
d_1 (in.)	Inside diameter of tubular conductor.
E	Relative emissivity of conductor surface ($E=1.0$ for a "black body").
I (amp.)	Current in conductor.
k, k_1	Skin effect ratio.
p (atmospheres)	Absolute pressure of air ($p=1.0$ for atmospheric pressure).
$q=\sqrt{\frac{k\,a_1}{k_1\,a}}$	Ratio used for the calculation of current-capacity.
R (ohms)	Resistance of conductor.
R_1 (microhms)	D-c. resistance per ft. of conductor.
r (ohms per mil-foot)	Specific resistance of conductor material.
T (deg. K.)	Absolute temperature of conductor.
T_a (deg. K.)	Average of absolute temperatures of conductor and air.
T_o (deg. K.)	Absolute temperature of surroundings.
Δt (deg. C.)	Temperature rise.
v (ft. per sec.)	Velocity of air crosswise to conductor.
w (watts per sq. in.)	Heat dissipation factor.
w_c (watts per sq. in.)	Component of heat dissipation factor due to convection.
w_r (watts per sq. in.)	Component of heat dissipation factor due to radiation.

Conductors in Still Air (Free Convection)

The heat which comes from the electrical losses in the conductor is dissipated in two ways: by convection and by radiation. Convection takes place because the air adjacent to the conductor becomes heated and tends to rise. When the surrounding air is still, as in a large closed room, all of the heat dissipated by convection is carried away by the natural air currents. It is estimated that when the temperature rise is about 30 deg. C. the velocity of the convection currents is of the order of 0.2 ft. per sec. for the smaller conductors (0.5 in. diameter) and 0.5 ft. per sec. for the larger conductors considered in this article.

The heat dissipated by convection per square inch of conductor surface for a given temperature rise depends upon the size and shape of the conductor, the smaller conductors dissipating heat more readily. The heat dissipated by radiation per square inch of conductor surface depends upon the absolute temperatures of the conductor and of the surroundings and upon the emissivity of the surface. In the case of a one-inch diameter copper conductor at 30 deg. C. rise, about two-thirds of the heat is dissipated by convection and one-third by radiation. For smaller conductors, the convection component is more than two-thirds; for larger conductors it is less than two-thirds of the total.

For the steady-state conditions,(2) the rate of heat dissipation is equal to the rate of heat supply which is the I^2R loss in the conductor. Thus

$$I^2R=wA \text{ watts} \qquad (1)$$

where

$$w=w_c+w_r \text{ watts per sq. in.} \qquad (2)$$

For the particular case of cylindrical conductors in air at atmospheric pressure and at 40 deg. C. when the temperature rise is 30 deg. C.

$$w_c=\frac{0.01805}{d\log_{10}\left[\frac{0.298}{d^{0.81}}+1\right]} \text{ watts per sq. in.} \qquad (3)$$

or when d is more than three inches

$$w_c=\frac{0.14}{d^{0.19}} \text{ watts per sq. in. (approx.)} \qquad (4)$$

Also

$$w_r=0.154\,E \text{ watts per sq. in.} \qquad (5)$$

Formulas (3), (4), and (5) were used to calculate the watts dissipated from the conductors for 30-deg. C. rise in a 40-deg. C. room temperature for the indoor condition (free convection).

For the calculation of the watts dissipated from indoor conductors (free convection), for any temperature rise, at any air temperature, the general formulas for long horizontal cylinders at pressure p (atmospheres) are as follows:

$$w_c=\frac{17.5\times10^{-6}\,T_a^{0.754}\,\Delta t\,\sqrt{p}}{d\log_e\left[\frac{0.0031\,T_a^{0.947}}{d^{0.81}\,\Delta t^{0.27}}+1\right]} \text{ watts per sq. in.} \qquad (6)$$

$$w_r=36.8E\left[(T/1000)^4-(T_o/1000)^4\right] \text{ watts per sq. in.} \qquad (7)$$

In either case the convection and radiation components are calculated separately and added to give the total watts w, according to Equation (2). The current is then calculated from Equation (1). A numerical example is given later.

Conductors Exposed to Moving Air (Forced Convection)

When the air surrounding a conductor is moving at velocity materially higher than the velocity of the currents due to free convection, the heated air adjacent to the conductor is carried away more rapidly and therefore the rate of heat dissipation due to convection (*i.e.*, forced convection as caused by winds, drafts, etc.) is greater for a given temperature rise. Under outdoor conditions the air velocity is generally more than 2 ft. per sec. unless the location is rather completely sheltered (wind velocity data are given below). This is from five to ten times the estimated velocity of the currents due to free convection as given.

For the particular case of cylindrical conductors in air at atmospheric pressure and at 40 deg. C. when the temperature rise is 30 deg. C. and the air velocity 2 ft. per sec. crosswise to the conductor the heat dissipated by convection is:

$$w_c=\frac{0.273}{\sqrt{d}} \text{ watts per sq. in.} \qquad (8)$$

The more general formula for the heat dissipated by forced convection for long horizontal cylinders in air at pressure p (atmospheres) and moving at a velocity v crosswise to the conductor is

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(2) It is sometimes necessary to consider the heating due to currents applied for a short time only, for instance during short-circuits. The subject is covered in an article entitled "Short-time Current Carrying Capacity of Copper Wire," by E. R. Stauffacher, GENERAL ELECTRIC REVIEW, June, 1928, p. 326.

$$w_c = \frac{0.0128 \sqrt{pv}}{T_a^{0.123} \sqrt{d}} \Delta t \text{ watts per sq. in.} \qquad (9)$$

This formula is an approximation applicable to diameters ranging from 0.3 in. to 5 in. or more when the velocity is considerably higher than the velocity of the air currents due to free convection. For low values of v the heat dissipated by convection approaches the value for free convection given by Formula (6).

The heat dissipated by radiation is the same as in still air and is given by Formula (5) for the particular case of 30-deg. C. rise, or Formula (7) for the general case.

Application of Theoretical Formulas to Practical Calculations

The formulas just given may be used for the calculation of both the temperature rise due to a given current and the current that will cause a given temperature rise. The data needed can be readily obtained by measurement, except the emissivity(3) which is usually obtained empirically. On the other hand, the coefficients used in the formulas may not always apply exactly to the conditions of conductors in service; for instance, in the case of free convection, the size of the room or enclosure makes a considerable difference. For this reason test data may not always agree exactly with the calculated results. However, in calculating current ratings or temperature rise it is well to make use of test data when available. The theoretical formulas are useful for cases not covered by test data and for checking test results.

A number of simplified formulas have been published which give approximate results within a limited range of conditions, for example, the empirical formula for current-carrying capacity given in the Overhead System Reference Book (Table 17, p. 80) of the N.E.L.A. In these formulas the total heat dissipated is generally expressed as a single function of temperature difference. Actually, the heat dissipated is made up of two components which follow different laws, as previously pointed out. Obviously such approximate formulas should not be used for conditions outside the range of conditions to which they apply; for instance, formulas applicable to large flat surfaces such as transformer tanks should not be used for small wires, and formulas intended only for wires should not be used for tubes several inches in diameter. Convenient formulas for the current-carrying capacity of cylindrical conductors with a given temperature rise are given in this article, and are used in connection with curves, the particular curves given here being for 30-deg. C. rise.

The theory of heating applies to insulated conductors as well as bare conductors, but the temperature rise of the conductor proper is the temperature rise at the surface of the insulation plus the temperature rise through the insulation, which depends upon the thickness and the heat conductivity of the material. In some cases an insulated conductor may carry more current with a given temperature rise than a similar conductor without insulation because the larger surface of the insulation and higher emissivity, if the insulation is black, may more than offset the temperature rise through the insulation.

FACTORS THAT AFFECT CONDUCTOR HEATING INDOORS

Conductors in large rooms or buildings free from drafts are surrounded by air which is practically still and therefore the temperature rise by test should be substantially the same as the temperature rise calculated by the formulas for free convection. In practice there are often a number of factors present that tend to reduce the temperature rise; for instance, intermittent loading, less than full-load current, drafts due to open windows, fans or rotating machinery, and cooler tap connections. In view of such factors as these, current ratings about 10 per cent higher than those obtained by test on long conductors in still air are sometimes permitted for design purposes.

On the other hand, factors are sometimes present which tend to increase the temperature rise, such as overloads, hot connecting members, and enclosures or compartments. In small enclosures such as compartments or ducts the free circulation of air is restricted and heat cannot be dissipated so readily as in larger enclosures. Consequently the temperature rise will be higher and the current that can be carried with a given temperature rise will be lower. Tests made in a closed compartment 6 ft. wide and 10 ft. high showed currents for 30-deg. C. rise that were 13 per cent lower for a 255,000 cir. mil. bare copper wire and 19 per cent lower for a 1,000,000 cir. mil. bare copper cable than the corresponding currents for 30-deg. C. rise in a large room with still air. If the ends of the compartments are open, longitudinal air currents may tend to reduce the temperature rise. Longitudinal air currents, however, have much less cooling effect than crosswise currents of the same velocity.

FACTORS THAT AFFECT CONDUCTOR HEATING OUTDOORS

Conditions of air temperature and air velocity are of course much more variable outdoors than indoors. Furthermore, conductors in outdoor service are exposed to the sun. The effects of wind and sun will be considered in detail.

Winds and Sheltering Effect of Buildings

The cooling effect of wind depends upon the velocity as shown by the theoretical formulas given for forced convection. The wind velocity at any particular location depends upon the general wind conditions and the sheltering effect of surroundings such as buildings, trees, and hills.

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(3) A table of values of emissivity is given in a paper entitled, "Effect of Color of Tank on Temperature," by V. M. Montsinger and L. Wetherill; abstract given in *A.I.E.E. Journal*, Nov., 1929, p. 824.

In this investigation a study was made of wind conditions at Schenectady, which is believed to be fairly typical of New York State locations, with view toward obtaining a representative minimum air velocity that can be used as a basis of current ratings for outdoor service. This study included consideration of wind conditions shown by a recording anemometer about 150 ft. above the ground and measurements made with a vane-type anemometer at several points on the ground and on the roof of a flat-top building.

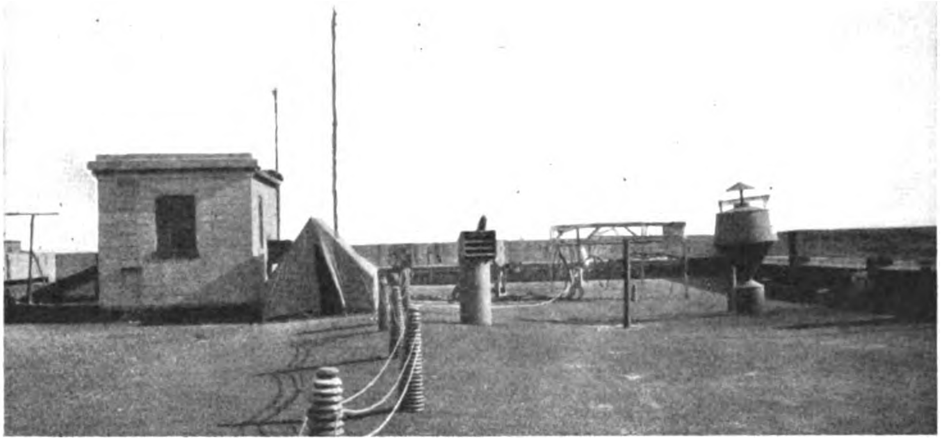

Fig. 1. View of Partly Sheltered Location No. 1 Used for Outdoor Heating Tests on Bare Copper Conductors

Anemometers Used. The recording anemometer mentioned is permanently located on a seven-story building which is higher than the surrounding buildings. The revolving cups are about 30 ft. above the roof and about 150 ft. above the ground. This instrument measures wind velocities irrespective of direction; and the records correspond to those kept at stations of the Weather Bureau. The records consist of ink marks on a moving strip of paper, each mark representating one mile of wind travel so that the number of marks in a one-hour period is the average velocity in miles per hour for that particular one-hour period.

The vane-type anemometers used in these investigations registered the air travel in feet, the average velocity being the number of feet divided by the corresponding time measured with a stop watch. It was found by trial that the minimum period over which a satisfactory average velocity can be obtained was about three minutes on account of gusts, eddies, and other variable conditions. These anemometers measured the air velocity in the direction of the axis of the vane. If the wind changed from north to south, for instance, the instrument would read backward. To avoid this condition, the anemometer was turned around when the vane started to turn backward so that the average velocity in the north and south direction, for example, was measured. A small amount of lost motion was of course unavoidable when making these reversals.

Effect of Location on Wind Velocity and Sheltering Effect of Buildings. Measurements of wind velocity were made between 1:45 and 2:45 p.m. on September 6, 1929 at the following locations: No. 1, the location used for heating tests shown in Fig. 1 on the roof of a building; No. 2, another point on the roof of the same building; Nos. 3 to 7, points on the ground as indicated in Figs. 2 to 4. At locations 2 to 7 the anemometer was held in the general direction of the air currents as indicated on the sketches. The velocities observed were as follows:

Average wind velocity by recording anemometer 150 ft. above ground................	15.4 ft./sec.
Wind velocities at Location No. 1 (Fig. 2)	
1:45 p.m., crosswise to conductors.......	3.3 ft./sec.
lengthwise " "	1.7 "
2:15 p.m., crosswise " "	3.0 "
lengthwise " "	1.0 "
2:45 p.m., crosswise " "	2.7 "
lengthwise " "	0.8 "
Wind velocity at Location No. 2 (Fig. 2).......	3.9 "
" " " " No. 3 " 2	2.3 "
" " " " No. 4 " 2	7.0 "
" " " " No. 5 " 2	3.0 "
" " " " No. 6 " 3	1.9 "
" " " " No. 7 " 4	4.5 "

These locations represent various degrees of sheltering. Nos. 1, 2, 3 and 5 represent partly sheltered locations. No. 6 shows somewhat more sheltering. No. 4 was in a passage of 25-ft. width between buildings where there is generally a strong air current. No. 7 was in a fairly large open space. It is seen that the average of the wind velocities at locations 1, 2, 3, and 5 is about one-fifth of the wind velocity at higher elevation.

In Figs. 5 and 6 wind velocity readings at location No. 1 are plotted covering a period of two or three

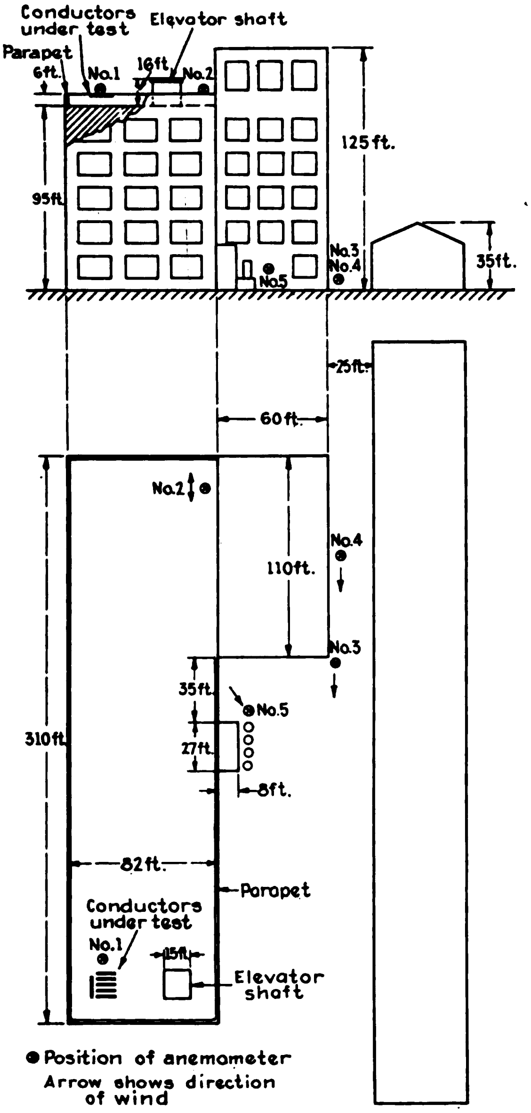
Conductors under test
Elevator shaft
Parapet
6ft.
No.1
16ft.
No.2
95ft.
125ft.
No.3
No.4
No.5
35ft.
25ft.
60ft.
No.2
No.4
110ft.
No.3
35ft.
No.5
27ft.
8ft.
310ft.
82ft.
Parapet
Conductors under test
No.1
15ft.
Elevator shaft
● Position of anemometer
Arrow shows direction of wind

Fig. 2. Diagram Showing Locations No. 1 to 5 at Which Wind Velocity Was Observed

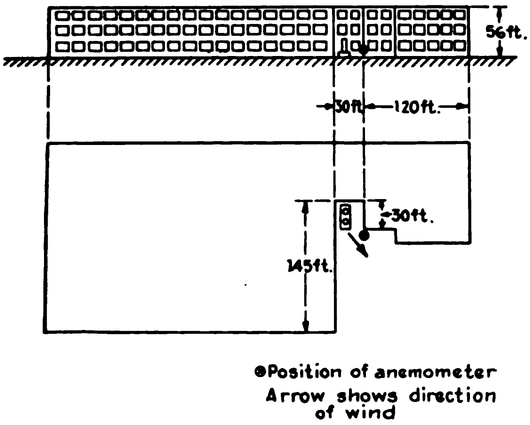
56ft.
30ft.
120ft.
30ft.
145ft.
●Position of anemometer
Arrow shows direction of wind

Fig. 3. Diagram Showing Location No. 6 at Which Wind Velocity Was Measured

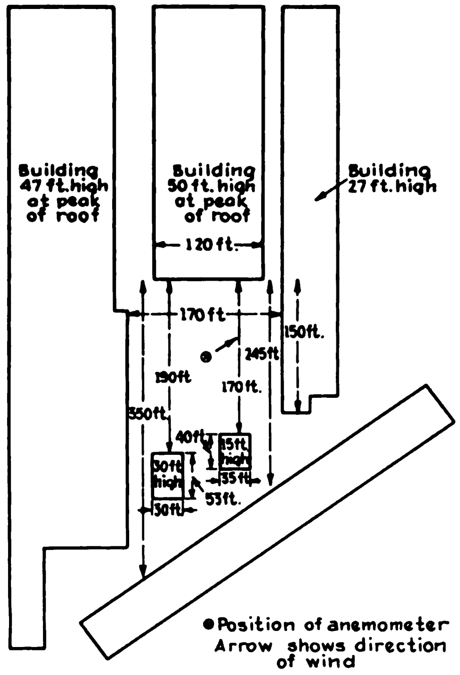
Building 47 ft. high at peak of roof
Building 50 ft. high at peak of roof
Building 27 ft. high
120 ft.
170 ft.
150ft.
145ft
190ft
170ft.
350ft.
40ft
15ft. high
30ft high
35ft
53ft.
30ft
●Position of anemometer
Arrow shows direction of wind

Fig. 4. Diagram Showing Location No. 7 at Which Wind Velocity Was Measured

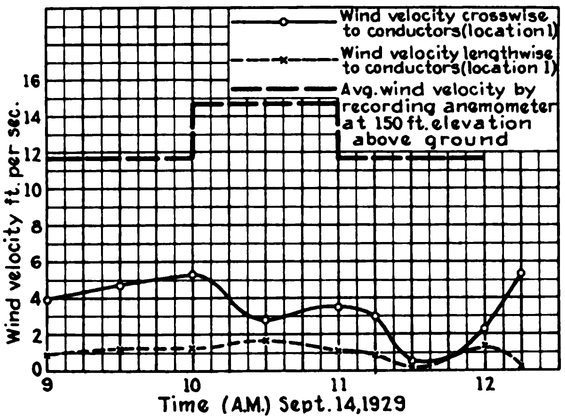

Fig. 5. Comparison of Wind Velocities at Location No. 1 (partly sheltered) with Wind Velocity at Higher Elevation

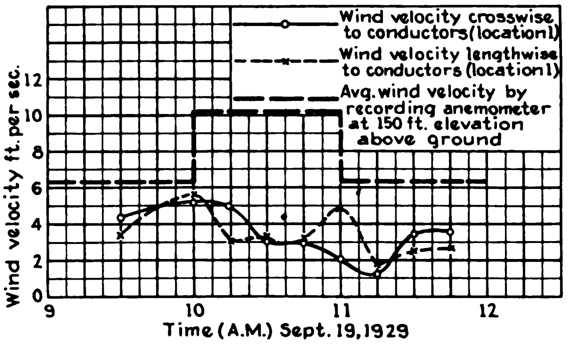

Fig. 6. Comparison of Wind Velocities at Location No. 1 (partly sheltered) with Wind Velocity at Higher Elevation

TABLE I

WIND VELOCITY MEASUREMENTS AT SCHENECTADY, N. Y.

Minimum Velocities for Period from June 1 to October 4, 1928. Measurements by Recording Anemometer 150 ft. Above Ground

Date	1 p.m.	2	3	4	5	6	7 a.m.	8	9	10	11	12	1	No. of 2-hr. Periods When Velocity Was Less Than 5 miles/hour
June 1–2	(Ave. 9 miles per hour)						4	3	3	14	14	–	–	1
5–6	*	*	*	5	3	4	2	3	3	3	2	4	–	4
7–8	*	*	4	4	7	5	5	10	4	2	2	3	–	3
12–13	*	*	3	3	5	6	1	1	2	2	6	2	–	3
July 6–7	*	*	*	*	*	*	1	2	2	†				1
17–18	*	*	*	*	*	*	6	*	*	*	*	*	–	0
20–21	*	*	*	*	*	*	2	2	*	*	*	*	–	1
23–24	2	3	3	3	2	3	2	2	3	5	8	*	–	4
25–26	*	*	*	*	*	*	3	2	4	4	3	3	–	3
26–27	2	5	5	3	5	4	2	2	2	3	2	2	3	3
30–31	*	*	*	*	*	*	1	0	3	5	5	5	8	1
Aug. 3–4	*	*	*	*	*	*	3	3	*	*	*	*	–	1
9–10	*	*	*	*	*	*	2	1	1	1	1	2	–	3
13–14	*	*	*	*	*	*	3	2	3	2	2	2	2	3
14–15	–	3	3	3	3	1	2	1	2	2	2	2	2	5
25–26	1	1	2	4	3	3	3	3	3	2	2	2	1	6
Sept. 6–7	3	2	2	3	3	3	2	1	3	3	3	3	3	6
7–8	–	3	3	3	3	2	2	2	2	2	*	*	–	4
12–13	*	*	*	*	*	*	*	4	5	3	1	0	7	1
15–16	*	4	4	3	4	3	2	4	13	*	*	*	–	3
17–18	*	*	*	*	*	*	1	2	4	3	4	3	3	3
Oct. 3–4	3	4	3	3	6	6	1	1	2	2	2	4	2	5
Total No. of 2-hr. periods														64
Total No. of hours for entire period														3000

*Wind velocity more than 5 miles per hour. †Record incomplete.

NOTE: The figures in the table give the average wind velocity in miles per hour for the one-hour period ending at the time indicated. The corresponding velocities in ft. per sec. are as follows:

1 mile per hr. = 1.465 ft. per sec. 4 miles per hr. = 5.87 ft. per sec.
2 miles per hr. = 2.93 ft. per sec. 5 miles per hr. = 7.33 ft. per sec.
3 miles per hr. = 4.40 ft. per sec. 6 miles per hr. = 8.80 ft. per sec.

TABLE II

WIND VELOCITY MEASUREMENTS AT SCHENECTADY, N. Y.

SEPTEMBER 3 TO 21, 1929

Measurements by Recording Anemometer as in Table I

	9 a.m.	10	11	12	1 p.m.	2	3	4	5	6	No. of 2-hr. Periods When Velocity Was Less Than 5 miles/hour
Sept. 3	†	3.5	9.5	15	17	19	13	19	17	16	0
4	3	3	4	4	5	6	6	6	8	4	2
5	4.5	4	5.5	3	4	3.5	6	5.5	14	13	2
6	8.5	9	8.5	8.5	8	10	10.5	10	7.5	7.5	0
7	5.5	3.5	2.5	2	1.5	2	4	4	10	4	3
8	3	3.5	5	4	6	4	3.5	3	2.5	2	3
9*	†	0	1	1	1	1	4	4	4.5	3.5	4
10	11	14	14	14	16.5	17	16	15	17	13	0
11	26.5	23.5	14.5	10	10.5	10	10	9.5	7.5	6.5	0
12	1.5	1.5	1.5	4	4.5	6.5	11.5	13	14	14	2
13	8	8.5	9	14	15	†	†	23	17	14	0
15	19	25	21	18	13.5	15	12	12	8	4	0
16	2	5	8.5	14	16	17	18	18	19	16	0
17	17	19	15	10	11	14	17	6.5	9	12	0
18	9	13	18	18	20	19	18	23	25	16	0
19	4	5	7	5	7	†	†	6	5	5	0
20	3	6	6	7	6	5	6	6	4	5	0
21	3	7	7	6	5	5	5	4.5	4	4	1
Total No. of 2-hr. periods											17
Total No. of hours for entire period											456

*Rain during morning. †Record not clear.

NOTE:—The figures in the table give the average wind velocity in miles per hour for the one-hour period ending at the time indicated (see Table I for corresponding velocities in ft. per sec.).

hours, measurements being made at intervals of 15 or 30 min. The average velocity crosswise to the conductors was from one-third to one-fourth of the wind velocity recorded by the anemometer at higher elevation. (Further data of a similar character are given in Table V.)

It appears from these data that the wind velocity at partly sheltered outdoor locations is from one-third to one-fifth of the wind velocity prevailing at an unsheltered location 150 ft. above the ground.

Analysis of Wind Velocity Variations throughout Summer Season. In order to examine wind-velocity data covering a full summer season, Table I was prepared from charts obtained during the period from June 1 to October 4, 1928. The charts which showed a minimum velocity of six miles per hour or more were eliminated. Those showing lower velocities were analyzed. In Table I each line represents entries covering an afternoon and the following morning, because each chart covered a 24-hr. period generally commencing at noon. In connection with conductor heating, only the periods of low velocity which occur during the daylight hours and which last, say, two hours or more are of particular interest. Referring to Table I it is seen that there were 64 two-hour periods during which the wind velocity was less than five miles per hour (7.3 ft. per sec.). The time represented by these periods of low wind velocity is 128 hr., or approximately five per cent of the total time, which was about 3000 hr.

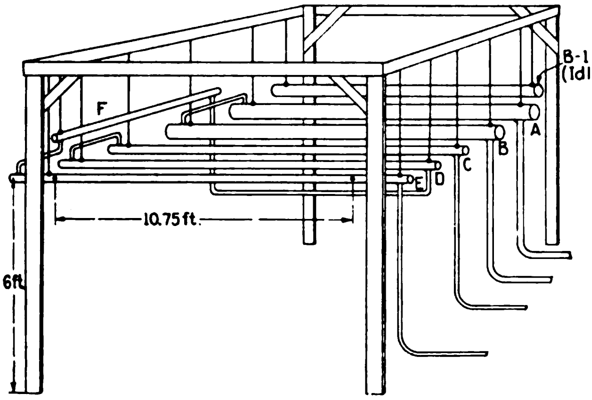

Fig. 7. Arrangement of Conductors for Outdoor Heating Tests
(See Table III for Dimensions of Conductors)

Table II is similar to Table I and shows wind velocities taken with the same anemometer 150 ft. above the ground from day to day for the period during which outdoor tests were made. During this period there were 14 two-hour periods when the wind velocity was less than five miles per hour. These periods represent about six per cent of the total time which is about the same percentage as in Table I.

If then the wind velocity at partly sheltered locations is taken as one-fourth of the values in Tables I and II, the velocity at such locations is more than two feet per second for about 95 per cent of the time.

In view of the figures given, the value of two feet per second has been chosen as a basis of current ratings for conductors in outdoor locations partly sheltered from the wind. This value of air velocity corresponds to about five miles per hour (7.3 ft. per sec.) measured at a point 150 ft. above the ground. In the tests presently to be described, the temperature rise of the conductors did not exceed the calculated value for a velocity of two feet per second except on a few of the occasions when the wind velocity was very low. The effect of the sun, to be later considered, is one of the factors tending to add to the temperature rise.

A coincidence of several conditions such as full load current, maximum air temperature, and minimum wind velocity would be required to give maximum conductor temperatures. The chances of coincidence are fairly small; for instance, some of the periods of low wind velocity occur on cloudy days or during rains. Warm, sunny days are generally favorable to air circulation on account of unequal heating of the air at different locations. The data on wind velocity, air temperature, and weather substantiate these points. Consequently, outdoor conductors in partly sheltered locations may be safely rated at current based on a wind velocity of two feet per second.

Values lower than two feet per second should be used for locations more completely sheltered and for locations where the air currents are normally lengthwise rather than crosswise to the conductors. On the other hand, conductors in unsheltered locations may be rated at currents based on wind velocities higher than two feet per second.

Heat Absorbed by Radiation from the Sun

Conductors exposed to the rays of the sun absorb heat by radiation. The temperature rise above the air temperature[4] is therefore higher than it would be if the sun were obscured, other conditions remaining the same. In the outdoor tests presently to be described, the additional temperature rise due to the sun was two to three deg. C. for conductors at about 30 deg. C. above the air temperature. At the same time, the temperature of an idle conductor exposed to the sun was eight deg. C. above the air temperature. The test data relating to the effect of sun are summarized in the section on Discussion of Results of Heating Tests.

DESCRIPTION OF OUTDOOR AND INDOOR HEATING TESTS

Outdoor Tests. The outdoor heating tests described here were made for the purpose of obtaining data under actual outdoor conditions. The general location of the conductors, already mentioned as Location

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[4] The air temperature out-of-doors was measured by thermometers exposed to freely circulating air but screened from the sun. This method of measuring the air temperature is used by the Weather Bureau (see *Physics of the Air*, by W. J. Humphreys; J. B. Lippincott Co.). Thermometers placed in the sun do not measure the true air temperature because the thermometers absorb heat radiated from the sun.

No. 1, is shown in Figs. 1 and 2. The conductors tested were suspended from the wooden frame as shown in Fig. 7. The location is fairly representative of a partly sheltered location, the sheltering being due to the parapet and the elevator shaft.

The test samples included solid and tubular copper conductors in lengths of about ten feet. These conductors are listed in Table III. The conductors were placed in a horizontal position and heated with 60-cycle alternating current. Tests were made nearly every day over a period of about three weeks. Heating was started each morning and readings were taken at half-hour intervals and sometimes oftener. The readings included current, watts input, temperatures of the conductors and of surrounding objects, the air temperature, and the air velocity. The temperatures of each conductor were measured by three thermocouples soldered to the copper, two at the mid-point and one at the quarter-point, and also by three thermometers similarly located and held with putty in the usual manner. The air temperature was measured by thermometers screened from the sun but exposed to freely circulating air. Other temperatures were measured by thermometers. Air velocities were measured by a vane-type anemometer as described. Measurements were made crosswise and lengthwise to the conductors, the average velocity being taken for a three-minute period.

Indoor Tests. After the outdoor tests had been completed the conductors were removed to the laboratory and set up for indoor tests. These tests were made in a large room 18 ft. high and free from drafts. The measurements aside from air velocity were similar to the measurements during the outdoor tests. The room temperature was measured by thermometers in oil cups of the usual type. The temperature rise was measured for several values of 60-cycle current.

Results of Heating Tests

The values of temperature rise obtained outdoors and indoors were plotted against the current values as shown in Figs. 8 to 12, inclusive. Curves for indoor conditions were plotted from the test data. Calculated curves were plotted for an air velocity of two feet per second crosswise to the conductors using a value of 0.5 for the emissivity of the copper. It will be noted that the calculated curve agrees very well with the test points at the minimum velocities.

The data for the outdoor tests are summarized in Table V. The test points have been given reference numbers used in the curves and in the table for the purpose of cross reference.

In Fig. 13 the values of heat losses in watts per square inch for 30-deg. C. rise are plotted against the diameter of the conductor. A curve for indoor (still air) conditions was plotted from the test data; the calculated curve will be considered later. A calculated curve for an air velocity of two feet per second, using 0.5 for the emissivity of copper as before, was also plotted. The latter curve is fairly representative of the test points at the minimum air velocities and is used as a basis of outdoor ratings for 30-deg. C. rise applicable to partly sheltered locations.

The curves of Fig. 13 show that the heat dissipation for 30-deg. C. rise (or any other specified rise)

TABLE III

PHYSICAL DATA FOR BARE COPPER CONDUCTORS USED FOR OUTDOOR AND INDOOR HEATING TESTS

Conductor Ref. Symbol	Nominal Size	DIAMETER		Length of Test Section (ft.)	Area of Conductor Surface (sq. in.)	Meas. Res. Referred to 20 deg. C. (microhms)	Per Cent Conductivity of Copper
		Outside (in.)	Inside (in.)				
A	2½ in. pipe	2.87	2.50	10.833	1175	66.8	82
B	....	1.59	1.40	8.50	510	176	89
C	....	0.75	0.63	10.0	283	626	100
D	No. 4/0 A.W.G.	0.46	....	11.0	192	534	100
E	½ in. pipe	0.84	0.625	10.75	337	450	79
F	No. 4/0 A.W.G.	0.46	....	8.052	139.5	392	100

The surface of the conductors at the time of the tests was smooth and somewhat darkened. During the two weeks' outdoor exposure of the conductors before the test, the original brightness of the surfaces had largely disappeared, and had been turned into a somewhat dull brown.

TABLE IV

EFFECT OF SUN UPON TEMPERATURE RISE OF CONDUCTORS CARRYING CONTINUOUS LOADS

Conductor	Diameter (in.)	Current (amp.)	Electrical Heating (watts/sq. in.)	TEMPERATURE RISE		Temperature Increase Due to the Sun
				Cloudy Weather (Wind Velocity 1.0 ft. per sec.)	Clear Weather (Wind Velocity 1.0 ft. per sec.)	
B-1*	1.59	0	0	0° C.	8° C.	8° C.
A	2.50	715	0.034	4	11	7
B	1.59	715	0.208	15	21.5	6.5
E	0.84	412	0.266	19	21.5	2.5
C	0.75	412	0.455	26	29	3
D	0.46	412	0.575	28	30	2

* Conductor B-1 was the idle conductor mentioned in Table IV. It consisted of an eight-foot length of the same tubing as Conductor B.

is not the same for all conductor sizes but decreases as the diameter increases. This is in accordance with the theoretical formulas given.

Effect of Sun. The data given in Table IV have been summarized from Table V for the purpose of showing the effect of the sun upon conductors with and without electrical heating.

The temperature readings given were selected for two occasions, the weather being cloudy on one occasion (see reference Nos. 5 to 11 in Table V)

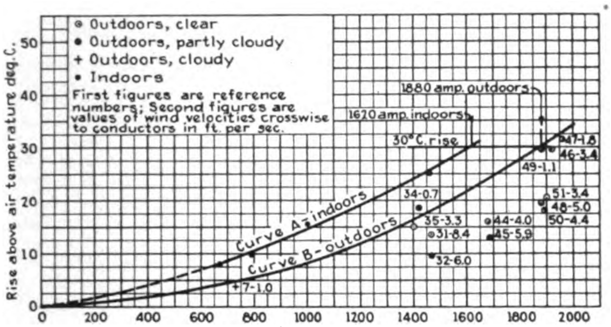

Fig. 8. Current *vs.* Temperature Rise Outdoors and Indoors. Conductor *A*, 2.87 in. outside diameter

Curve A: Temperature rise indoors, by test.
Curve B: Temperature rise outdoors, calculated for wind velocity of two feet per second crosswise to conductors.

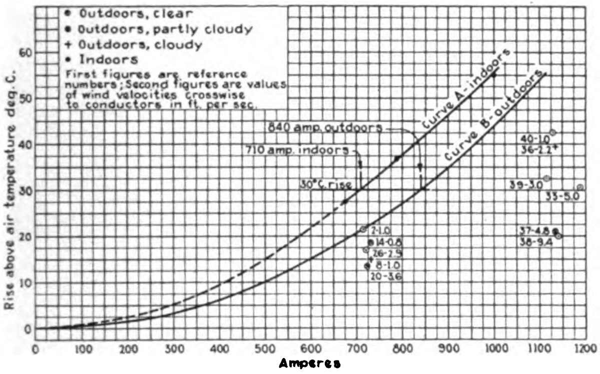

Fig. 9. Current *vs.* Temperature Rise Outdoors and Indoors. Conductor *B*, 1.59 in. outside diameter

Curve A: Temperature rise indoors, by test.
Curve B: Temperature rise outdoors, calculated for wind velocity of two feet per second crosswise to conductors.

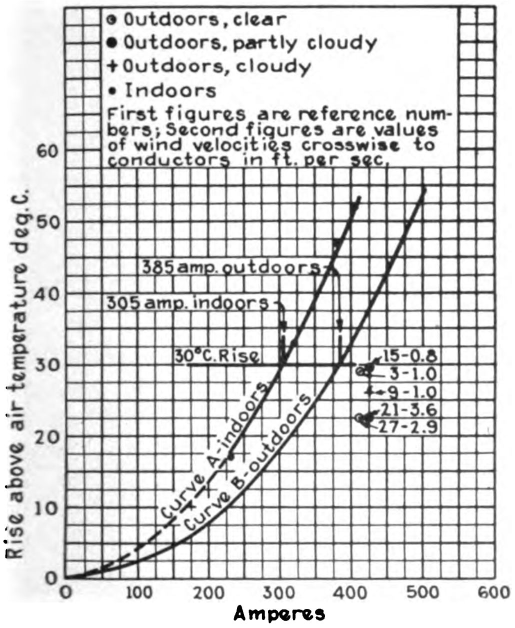

Fig. 10. Current *vs.* Temperature Rise Outdoors and Indoors. Conductor *C*, 0.75 in. outside diameter

Curve A: Temperature rise indoors, by test.
Curve B: Temperature rise outdoors, calculated for wind velocity of two feet per second crosswise to conductors.

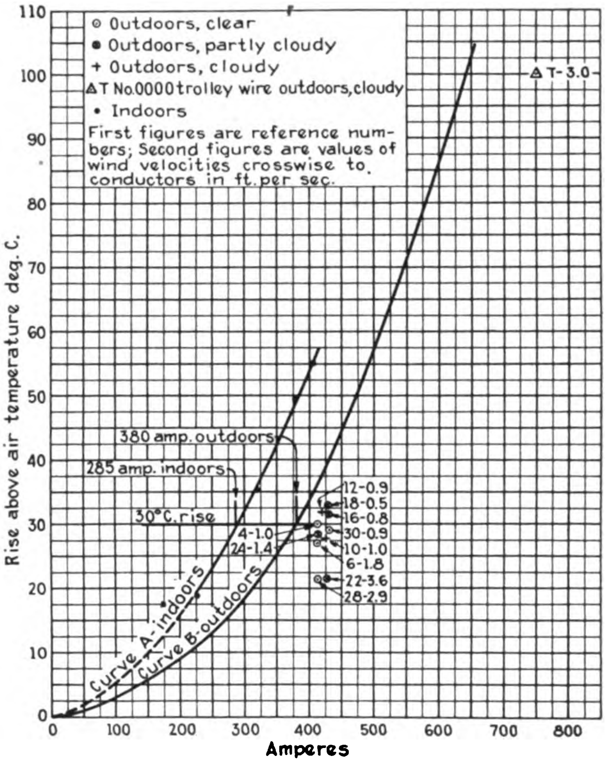

Fig. 11. Current *vs.* Temperature Rise Outdoors and Indoors. Conductors *D* and *F*, No. 0000 A.W.G., 0.46 in. outside diameter

Curve A: Temperature rise indoors, by test.
Curve B: Temperature rise outdoors, calculated for wind velocity of two feet per second crosswise to conductors.

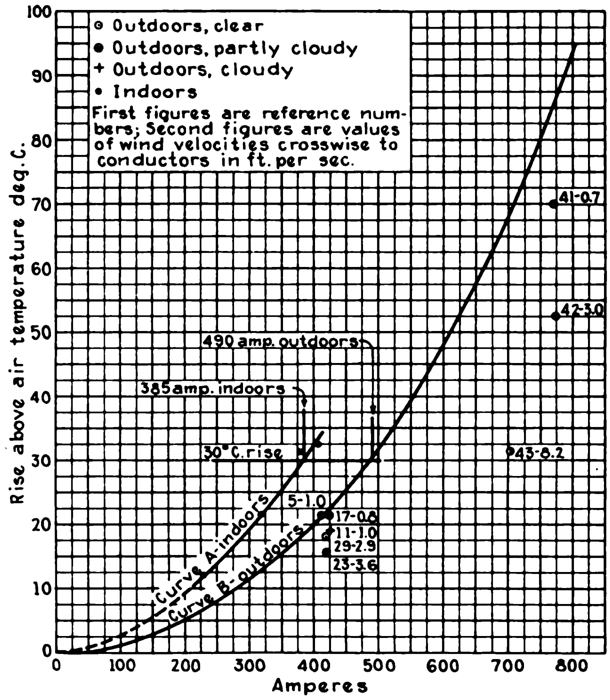

Fig. 12. Current *vs.* Temperature Rise Outdoors and Indoors. Conductor *E*, 0.84 in. outside diameter

Curve A: Temperature rise indoors, by test.
Curve B: Temperature rise outdoors, calculated for wind velocity of two feet per second crosswise to conductors.

TABLE V: SUMMARY OF DATA FOR OUTDOOR TESTS

This Table gives selected readings for fairly steady wind conditions. Actual observations were made every half hour or oftener

Ref. No.	Date and Time	Conductor	Outside Diam. (in.)	Temp. of Conductor (deg. C.)	Temp. of Air (deg. C.)	Temp. Rise Above Air (deg. C.)	Temp. of Idle Conductor (deg. C.)	Current (amp.)	Heat Loss (watts per sq. in.)	Watts per sq. in for 30-deg. C. Rise	Wind Velocity Crosswise to Conductors (ft. per sec.)	Wind Velocity Lengthwise to Conductors (ft. per sec.	Average Wind Velocity for One-hour Period† (ft. per sec.)	Humidity Per Cent	Weather
1	Sept. 4, 1:00 p.m.	A	2.87	45	34*	11	42.0	715	0.034	....	1.0	1.8	7.3	63	Clear
2	“ “ “ “	B	1.59	55.5	“	21.5	“	“	0.208	0.290	“	“	“	“	“
3	“ “ “ “	C	0.75	63	“	29	“	412	0.455	0.470	“	“	“	“	“
4	“ “ “ “	D	0.46	64	“	30	“	“	0.575	0.575	“	“	“	“	“
5	“ “ “ “	E	0.84	55.5	“	21.5	“	“	0.266	0.371	“	“	“	“	“
6	“ “ “ “	F	0.46	61	“	27	“	“	0.574	0.638	1.8	1.0	“	“	“
7	Sept. 5, 11:00 a.m.	A	2.87	27	23.0	4	23.0	730	0.031	0.236	1.0	0.9	8.0	84	Cloudy
8	“ “ “ “	B	1.59	38	“	15	“	“	0.201	0.402	“	“	“	“	“
9	“ “ “ “	C	0.75	49	“	26	“	425	0.463	0.535	“	“	“	“	“
10	“ “ “ “	D	0.46	51	“	28	“	“	0.578	0.620	“	“	“	“	“
11	“ “ “ “	E	0.84	42	“	19	“	“	0.266	0.420	“	“	“	“	“
12	“ “ “ “	F	0.46	55	“	32	“	“	0.594	0.557	0.9	1.0	“	“	“
13	Sept. 5, 2:00 p.m.	A	2.87	33	25.5	8.5	29.0	730	0.032	....	0.8	0.5	5.1	84	Partly Cloudy
14	“ “ “ “	B	1.59	44	“	18.5	“	“	0.206	0.334	“	“	“	“	“ “
15	“ “ “ “	C	0.75	55	“	29.5	“	425	0.470	0.478	“	“	“	“	“ “
16	“ “ “ “	D	0.46	57	“	31.5	“	“	0.593	0.565	“	“	“	“	“ “
17	“ “ “ “	E	0.84	47	“	21.5	“	“	0.272	0.379	“	“	“	“	“ “
18	“ “ “ “	F	0.46	58.5	“	33	“	“	0.605	0.550	0.5	0.8	“	“	“ “
19	Sept. 6, 10:00 a.m.	A	2.87	26	21.5	4.5	23.0	723	0.030	....	3.6	1.4	13.2	85	“ “
20	“ “ “ “	B	1.59	35	“	13.5	“	“	0.193	0.426	“	“	“	“	“ “
21	“ “ “ “	C	0.75	44	“	22.5	“	420	0.438	0.585	“	“	“	“	“ “
22	“ “ “ “	D	0.46	43	“	21.5	“	“	0.546	0.760	“	“	“	“	“ “
23	“ “ “ “	E	0.84	37	“	15.5	“	“	0.255	0.494	“	“	“	“	“ “
24	“ “ “ “	F	0.46	50	“	28.5	“	“	0.570	0.600	1.4	3.6	“	“	“ “
25	Sept. 6, 2:30 p.m.	A	2.87	39	29.0	10	35.5	720	0.031	....	2.9	0.9	15.4	85	Clear
26	“ “ “ “	B	1.59	46	“	17	“	“	0.202	0.356	“	“	“	“	“
27	“ “ “ “	C	0.75	51.5	“	22.5	“	420	0.454	0.605	“	“	“	“	“
28	“ “ “ “	D	0.46	50.5	“	21.5	“	“	0.565	0.788	“	“	“	“	“
29	“ “ “ “	E	0.84	47	“	18	“	“	0.266	0.443	“	“	“	“	“
30	“ “ “ “	F	0.46	58	“	29	“	“	0.592	0.612	0.9	2.9	“	“	“
31	Sept. 10, 3:15 p.m.	A	2.87	44	30.5	13.5	37	1464	0.134	0.296	8.4	1.0	22.0	..	Clear
32	Sept. 11, 11:00 a.m.	“	“	25.5	16	9.5	19.5	1465	0.125	0.395	6.0	5.2	21.2	..	Partly Cloudy
33	Sept. 11, 4:00 p.m.	B	1.59	50.5	20	30.5	26.5	1190	0.561	0.552	5.0	2.7	13.9	78	Clear
34	Sept. 12, 11:00 a.m.	A	2.87	37	18.5	18.5	22.5	1420	0.123	0.200	0.7	0.5	2.2	84	Partly Cloudy
35	Sept. 12, 3:30 p.m.	“	“	38	23	15	30	1400	0.120	0.240	3.3	1.4	19.0	..	Clear
36	Sept. 13, 10:30 a.m.	B	1.59	57.5	18	39.5	20	1135	0.528	0.401	2.2	0.7	13.2	..	Cloudy
37	Sept. 13, 1:30 p.m.	“	“	43	22	21	24	“	0.495	0.706	4.8	1.7	....	..	Partly Cloudy
38	Sept. 13, 4:00 p.m.	“	“	43	23	20	24.5	1140	0.500	0.750	9.4	3.1	34	..	Clear
39	Sept. 14, 11:15 a.m.	“	“	55.5	23	32.5	25.5	1115	0.505	0.467	3.0	0.9	11.7	84	“
40	Sept. 14, 11:45 a.m.	“	“	65.5	23.5	42.5	26.5	1130	0.540	0.381	1.0	0.7	11.7	84	“
41	Sept. 16, 9:30 a.m.	E	0.84	90	15	75	17	770	0.946	0.378	0.7	0.2	5.9	..	“
42	Sept. 16, 11:00 a.m.	“	“	73	20.5	52.5	27	774	1.00	0.572	3.0	1.0	12.4	59	“
43	Sept. 16, 2:00 p.m.	“	“	56.5	25	31.5	30	705	0.784	0.746	8.2	2.5	25.0	..	“
44	Sept. 18, 11:00 a.m.	A	2.87	31	15	16	20	1680	0.168	0.317	4.0	3.6	26.4	68	“
45	Sept. 18, 3:30 p.m.	“	“	29.5	16.5	13	21.5	1684	0.167	0.385	5.9	4.3	33.7	..	Partly Cloudy
46	Sept. 19, 11:30 a.m.	“	“	42	12.5	29.5	22.5	1920	0.228	0.230	3.4	2.5	7.3	59	Clear
47	Sept. 19, 4:30 p.m.	“	“	47.5	16	31.5	26.5	1960	0.242	0.230	1.8	3.0	7.3	..	“
48	Sept. 20, 11:00 a.m.	“	“	31	11.5	19.5	16	1880	0.222	0.340	5.0	4.5	8.8	..	“
49	Sept. 20, 2:30 p.m.	“	“	45	15.5	29.5	25.5	“	0.222	0.225	1.1	0.2	8.8	62	“
50	Sept. 21, 10:00 a.m.	“	“	27	9	18	13	1890	0.208	0.348	4.4	1.0	10.2	69	“
51	Sept. 21, 11:20 a.m.	“	“	33	12.5	20.5	18	1900	0.216	0.315	3.4	1.6	8.8	..	“

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* Maximum temperature for the day 36 deg. C. (97 deg. F.) from records of the Weather Bureau Station at Albany, N. Y.

† Measured by recording anemometer 150 ft. above ground.

and clear on the other occasion (see reference Nos. 1 to 5). In Table IV the conductors have been listed in order of temperature rise without the sun (cloudy weather). It will be seen that there is a consistent decrease of heating due to the sun as the temperature rise above the air becomes higher. Thus the temperature of conductor D, which was 28 deg. C. above the air temperature in the absence of sunshine, was increased only two degrees C. by the sun, while the temperature of the idle conductor (B-1) which had no other source of heat besides the sun was increased by eight degrees C. Results of a similar character have been obtained in previous investigations. Thus it appears that the heating effect of the sun upon conductors at 30-deg. C. rise is not so great as upon conductors at lower temperatures above the air.

The heating effect of the sun is also shown by the test points on Figs. 8 to 12, the presence or absence of sunshine being indicated by the symbols used. It will be noted that the temperature rise with sunshine was generally less than the temperature rise calculated for an air velocity of two feet per second except on a few occasions when the air velocity was lower than this.

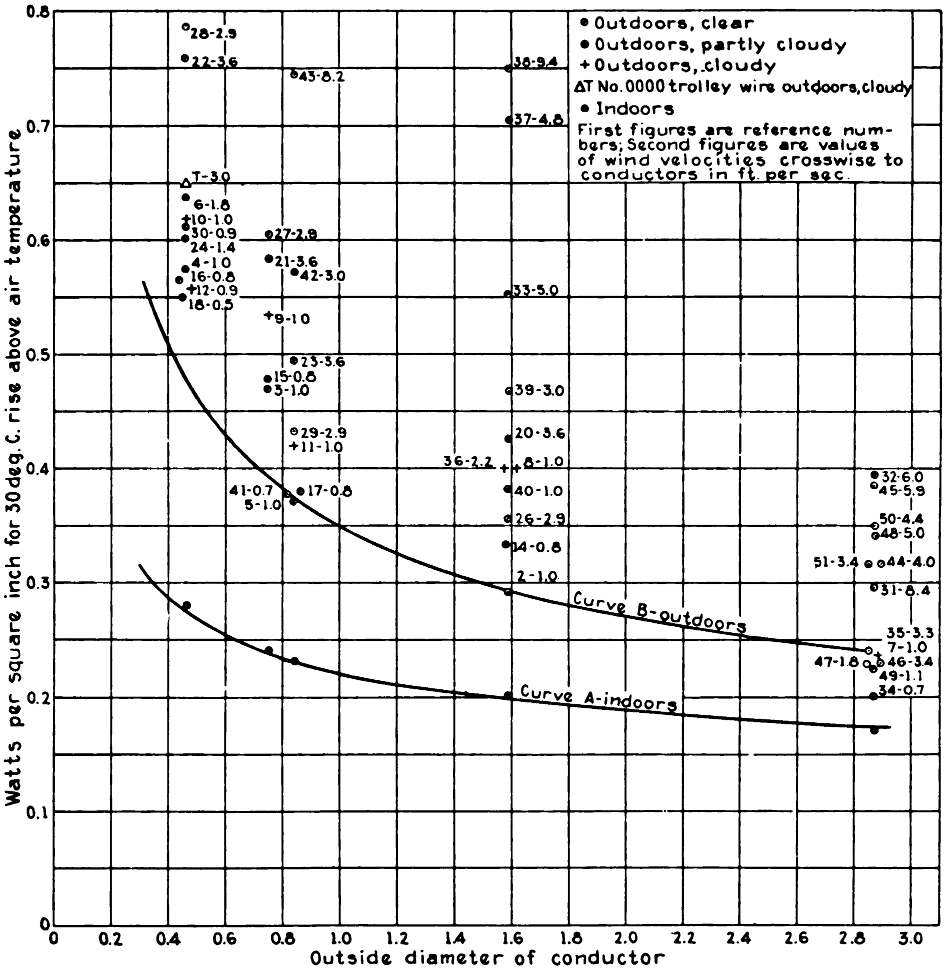

Fig. 13. Watts per Square Inch for 30-deg. C. Temperature Rise *vs.* Conductor Diameter. Conductors *A* to *F*.

Curve A: Indoors, by test. *Curve B:* Outdoors, calculated for wind velocity of two feet per second crosswise to conductors.

Since the temperature increase due to the sun when the temperature rise was of the order of 30 deg. C. was two to three deg. C. when the idle conductor showed a rise of 8 deg. C., and since the temperature rise of the conductors in the sun was generally less than the temperature rise calculated for an air velocity two feet per second, it is concluded that current ratings for 30-deg. C. rise in locations partly sheltered from the wind can be determined as a first approximation and without serious error on the basis of an air velocity of two feet per second without making separate allowance for the effect of the sun.

When desired, the effect of sun may be separately taken into account in accordance with the data in Table V. In tropical climates the effect of the summer sun would, of course, be somewhat greater because of the increased intensity of solar radiation, as compared with that prevailing at 40 deg. northern latitude during September.

Comparison of Test Results with Other Data

In Fig. 14 the curve of watts per square inch for 30-deg. C. rise indoors from Fig. 13 is compared with a curve calculated by Formulas (3) and (5) for still air.

The curves agree very well for the smaller sizes of conductors, but not quite so well for the larger sizes, the maximum difference being about 10 per cent. The difference may, at least partly, be accounted for by the value of emissivity used in the calculations, which value was 0.5. Since the emissivity of the conductors used in the heating tests was not measured, and since they were not exposed outdoors for a very long time it may be expected that their emissivity was somewhat lower than 0.5. Values given(3) range from 0.15 for bright copper to 0.60 for oxidized copper. The value of 0.5 was used in establishing outdoor ratings because of the relatively rapid oxidation of outdoor copper conductors. In determining indoor ratings, however, the test data (Curve A, Fig. 14) rather than calculated data were used.

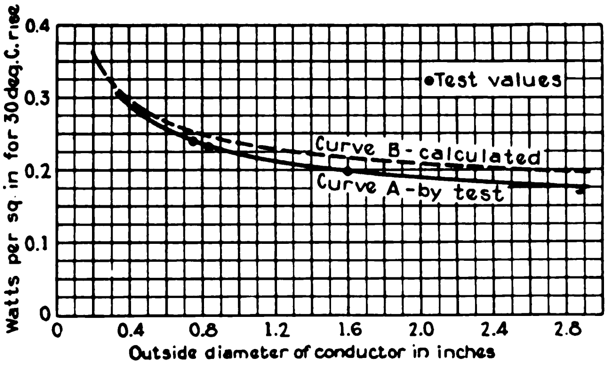

Fig. 14. Watts Per Square Inch for 30-deg. C. Temperature Rise *vs.* Conductor Diameter, Indoors

Curve A: By test: conductors *A* to *F*.
Curve B: Calculated by formulas for still air.

In Fig. 15 the results of the indoor tests made during this investigation are compared with similar test data from a number of different sources. The dotted curve was published by G. E. Luke.(5) It agrees very well with the test curve obtained here for conductor diameters between 0.7 in. and 1.3 in. but less closely for smaller diameters, the difference being about 20 per cent for the diameter, corresponding to No. 0 A.W.G. wire (0.325 in. diameter). Accordingly, in tables of current values based upon Luke's curve the current value given for No. 0 wire for 30-deg. C. rise is about 10 per cent higher than the corresponding value given here.

Test values obtained by Melsom and Booth(6) for a 0.75 in. diameter bright copper rod and for the same rod painted black are also shown in Fig. 14. The point for the bright conductor falls below the test curve and the point for the black conductor falls above the curve, as would be expected.

Test values obtained by R. J. C. Wood(7) for three sizes of aluminum cable have been plotted. Two of the cables were new and the third was taken from service. The surface of the used conductor was covered with a hard, smooth, black deposit. The point for the black conductor is above the test curve and the others are below the curve, as would be expected.

Test values for three sizes of bare copper cables obtained by Woll and Gable(8) at the Massachusetts Institute of Technology are also plotted. Two of the points agree very well with the curve; but the other point, which represents a 500,000-circular mil cable, falls considerably below the curve. The condition of the cables was not stated and it is possible that this particular cable may have been new.

Other points include No. 4/0 trolley wire and two sizes of aluminum cable from tests made at Schenectady several years ago. The trolley wire mentioned was also tested out-of-doors, and the temperature rise was 100 deg. C. at 800 amp. when the wind velocity was three feet per second and the sun was obscured. This point is indicated on Fig. 11 and the dissipation in watts per sq. in. for 30-deg. C. rise is indicated in Fig. 13, showing reasonably good agreement with the results obtained in this investigation.

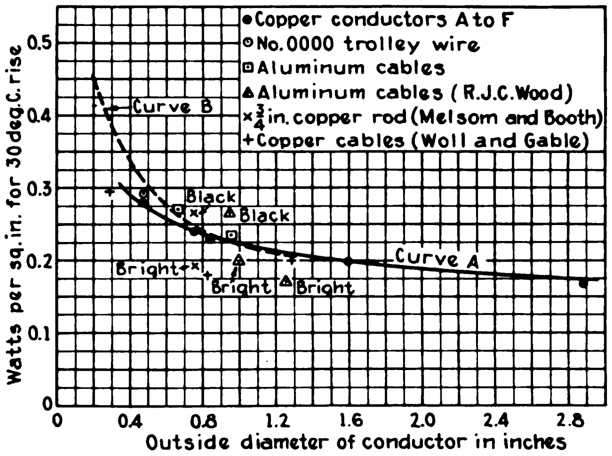

Fig. 15. Values of Watts Per Square Inch for 30-deg. C. Rise Indoors Obtained in This Investigation and in Other Investigations

Curve A: By test indoors.
Curve B: From curve published by G. E. Luke.

It is well known that the method of measuring temperatures makes a considerable difference in the results. It was found, for example, in the indoor tests that the temperatures by thermocouple were two or three degrees higher than the temperatures by thermometer. The temperatures by thermocouple were used in obtaining the results since they correspond most nearly to the actual temperatures of the conductors. Under outdoor conditions, however, the difference between the thermocouple readings and the thermometer readings was not so consistent and therefore averages of the readings by both methods were taken.

It is of interest to compare the results of tests in a room with drafts produced by fans, reported by R. J. C. Wood,(7) with values calculated by the formulas for forced convection. The results are given in Table VI.

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(5) "Cooling of Machines," by G. E. Luke, *A.I.E.E. Trans.*, Vol. 42, 1923, p. 639.

(6) "Current-carrying Capacity of Solid Bare Copper and Aluminum Conductors," by S. W. Melsom and H. C. Booth, *Jour. I.E.E.*, Nov., 1924, p. 909.

(7) "Heating of Large Steel-cored Aluminum Conductors," by R. J. C. Wood, *A.I.E.E. Trans.*, Vol. 43, 1924, p. 1258.

(8) "Current-carrying Capacity of Bare Cables," by W. M. Woll and J. A. Gable, *Electric Journal*, Vol. 23, 1926, p. 557.

In making the calculations the emissivity was taken as 0.9 for the black conductor and 0.5 for the new conductor. The calculated results show satisfactory agreement with the test values.

CURRENT-CARRYING CAPACITY

Tables of Current-carrying Capacity for 30-deg. C. Rise

Values of current-carrying capacity for 30-deg. C. rise have been determined from the heating data given here for a number of conductor sizes in common use. The values are given in Table VII. Tables for other values of temperature rise can be prepared in a similar manner. Table VII applies to copper of 100 per cent conductivity; the relative current-carrying capacities for conductors of lower conductivity copper and of aluminum are given in Table VIII.

TABLE VI

COMPARISON OF RESULTS

Conductor	WATTS PER SQ. IN. FOR 30-DEG. C. RISE	
	$v = 1.62$ ft./sec.	$v = 2.84$ ft./sec.
605,000-cir. mil aluminum cable 0.954 in. diameter, black		
By test	0.440	0.505
By calculation	0.39	0.48
660,000-cir. mil aluminum cable 1.00 in. diameter, new		
By test	0.345	0.413
By calculation	0.32	0.40

The current values for indoor service were determined from the test curve for indoor conditions on Fig. 13, and will give 30-deg. C. rise in a large room without drafts. In small compartments and ducts these current values will give a greater rise, with respect to the air temperature outside of the duct or compartment.

The current values given in Table VII for outdoor service were derived from Curve B, Fig. 13, calculated with the aid of Formulas (5) and (8) for an air velocity of two feet per second, and apply to partly sheltered locations for weather conditions similar to those prevailing in Schenectady. Under these conditions the temperature rise will not exceed 30 deg. C. except at times of abnormally low wind velocity which occur less than five per cent of the time during the summer season. The temperature rise is referred to the air temperature, which is measured by thermometers exposed to the air but screened from the sun. The value of 40 deg. C. has been used for the air temperature outdoors as a basis for current ratings, since this value is commonly employed.

In the last column of Table VII is shown the percentage increase of the outdoor current ratings over the corresponding indoor current ratings for still air. The increase ranges from 14 per cent for tubes of 4.5-in. diameter to 35 per cent for wires of the size of No. 0 A.W.G.

Current ratings lower than those given in Table VII for outdoor service are to be used for locations with more than usual sheltering or when the normal air currents are lengthwise rather than crosswise to the conductors.

TABLE VII

CURRENT RATINGS FOR 30-DEG. C. TEMPERATURE RISE

Bare Conductors, 100 Per Cent Conductivity Copper in Horizontal Position; 40 deg. C. Air Temperature

NOTE: The current values for indoor service apply to conductors in a large room without drafts; the current values for outdoor service apply to conductors in partly sheltered locations and are based on a wind velocity of 2 ft. per sec.

60 CYCLES

ITEM 1: SOLID WIRE

Size (A.W.G.)	Outside Diameter (in.)	CURRENT RATING		Per Cent Increase for Outdoor Service
		Indoor (amp.)	Outdoor (amp.)	
0	0.325	178	240	35
00	0.365	208	280.	35
0000	0.480	285	380	33

ITEM 2: STRANDED CABLE

Size (A.W.G.)	Outside Diameter (in.)	Indoor (amp.)	Outdoor (amp.)	Per Cent Increase for Outdoor Service
0	0.373	184	248	35
00	0.418	216	286	32
0000	0.528	296	388	31
Cir. Mils				
250,000	0.575	331	434	31
400,000	0.728	456	583	27
600,000	0.893	608	756	25
750,000	0.998	692	868	25
1,000,000	1.152	836	1038	24

ITEM 3: TUBULAR CONDUCTORS

Standard Pipe Sizes

Nominal Size	Outside Diameter (in.)	Inside Diameter (in.)	CURRENT RATING		Per Cent Increase for Outdoor Service
			Indoor (amp.)	Outdoor (amp.)	
½	0.840	0.625	433	550	27
¾	1.050	0.822	545	680	25
1	1.315	1.062	740	910	23
1¼	1.660	1.368	913	1090	20
1½	1.900	1.600	985	1190	20
2	2.375	2.062	1345	1585	18
2	2.875	2.500	1760	2060	17
3	3.500	3.062	2240	2600	16
3½	4.000	3.500	2650	3040	14.5
4	4.500	4.000	2970	3400	14

ITEM 4: TUBULAR CONDUCTORS

Extra Heavy Pipe Sizes

Nominal Size	Outside Diameter (in.)	Inside Diameter (in.)	CURRENT RATING		Per Cent Increase for Outdoor Service
			Indoor (amp.)	Outdoor (amp.)	
½	0.840	0.542	490	620	27
¾	1.050	0.736	615	770	25
1	1.315	0.951	818	1010	23
1¼	1.660	1.272	1050	1270	21
1½	1.900	1.494	1210	1460	20
2	2.375	1.933	1560	1850	18
2½	2.875	2.315	2040	2390	17
3	3.500	2.892	2580	3000	16
3½	4.000	3.358	2980	3410	14.5
4	4.500	3.818	3400	3880	14

Formulas for Current-carrying Capacity

Formulas (10) and (12) are intended to be used for determining the current-carrying capacity of round conductors of non-magnetic material having outside diameters between 0.3 and 4.5 in. The current values, in Table VII have been computed by these formulas, using values of watts per sq. in. (w) taken from Fig. 13 as previously stated. The formulas are derived by substituting values of resistance (R) and area of surface (A) for a conductor one foot long in Equation (1). Thus

$$I^2k\,R_1 \times 10^{-6} = 12\pi\,d\,w$$

Solving for the current

$$I = \frac{1000\sqrt{12\pi\,d\,w}}{\sqrt{kR_1}}$$

or

$$I = \frac{C}{\sqrt{kR_1}}\ \text{amp.} \qquad (10)$$

where

$$C = 6140\sqrt{d\,w} \qquad (11)$$

The symbols here used were defined in the section headed "Theory of Continuous Heating."

Values of resistance per foot of conductor are given in standard wire tables. (9)

For rods and tubes it is sometimes convenient to use the specific resistance of the material in ohms per mil-foot. Since

$$R_1 = \frac{r}{d^2 - d_1^2}\ \text{microhms}$$

Formula (10) becomes

$$I = C\sqrt{\frac{d^2 - d_1^2}{kr}}\ \text{amp.} \qquad (12)$$

For solid rods or wires $d_1 = 0$.

Values of the factor C for 30-deg. C. rise outdoors and indoors are given in Fig. 16 for conductor diameters ranging from 0.3 in. to 4.5 in. Similar curves can be plotted for other values of temperature rise.

Copper Conductors of High Conductivity

For conductors of high-conductivity copper (97 to 100 per cent) values of current for 30-deg. C. rise can be taken directly from Table VII. For sizes of conductors not included in the table, Formula (10) or Formula (12) may be used with the proper value of resistance at the operating temperature, considered as 70 deg. C. in computing the current values for Table VII. The temperature coefficient of resistance for 100 per cent conductivity copper is 0.00393 referred to 20 deg. C. The value of the specific resistance (r) is 12.59 ohms per mil-foot at 70 deg. C.

Correction for Cross-sectional Area and Skin Effect. Current values are given in Table VII for nominal iron pipe sizes of tubes having the dimensions specified by one of the manufacturers of copper tubing. For tubes *of a given outside diameter* but differing slightly from the dimensions given the value of current taken from the table may be multiplied by the ratio

$$q = \sqrt{\frac{ka_1}{k_1a}} \qquad (13)$$

where a_1 = area of copper cross section of tube of same outside diameter as tube of area a given in the table

k_1 = skin effect ratio for tube of area a_1

Copper Conductors of Less than 100 Per Cent Conductivity

Table VIII gives the relative current-carrying capacity (taken as 1.0 for standard copper) for conductivities down to 50 per cent. Multiplying the current values based on 100 per cent conductivity copper, as from Table VII, by the relative current-carrying capacity gives the corresponding current values for conductors of the conductivity specified. In calculating the data for Table VIII the conductor temperature was considered as 70 deg. C. and the temperature coefficient of resistance was considered as proportional to the conductivity. (10)

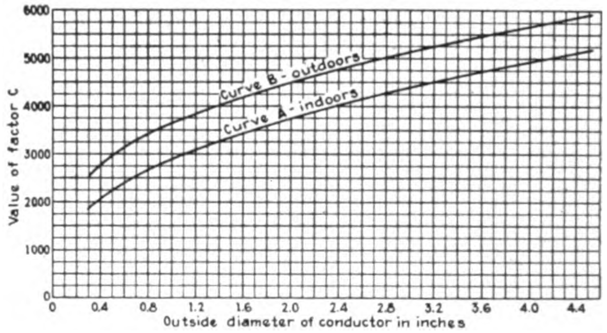

Fig. 16. Values of Factor *C* in Formulas (10) and (12) for Current-carrying Capacity of Round Conductors Limited to 30-deg. C. Rise

Curve A: Indoors, large enclosures without drafts.
Curve B: Outdoors, partly sheltered locations.

Aluminum Conductors

Tests have shown that aluminum conductors dissipate heat at about the same rate as copper conductors of the same outside diameter when the temperature rise is the same. Therefore, the current value for 30-deg. C. rise for an aluminum conductor of the same actual size as a copper conductor in Table VII may be obtained by multiplying the current value for the copper conductor by the relative current-carrying capacity for aluminum of the proper conductivity from Table VIII.

Rectangular Conductors

Rectangular bars are sometimes used for buses and connections in outdoor stations. Consideration of rectangular conductors was not included in this investigation. Theoretical formulas for the heating of rectangular conductors have been worked out but the application is not so simple as in the case of round conductors, especially in the case of laminated bars. It is probable that increases of current of the order of 10 per cent over the corresponding currents for still air are possible.

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(9) For copper wire tables see Circular No. 31 of the Bureau of Standards.

For skin effect ratio of wires see Scientific Paper No. 169, Bureau of Standards (p. 174, Formula 143, and the table on p. 226) or the article on Skin Effect in *Pender's Handbook*. The skin effect ratio for round cables is the same as for wires of the same cross section of metal. See also "Skin Effect and Promixity Effect in Tubular Conductors," by H. B. Dwight, *A.I.E.E. Trans.*, Vol. 41, 1922, p. 189.

(10) See Circular No. 31, Bureau of Standards, p. 10.

TABLE VIII
RELATIVE CURRENT-CARRYING CAPACITIES

For Conductors of the Same Diameter and Cross-section of Metal Having Different Values of Conductivity

CONDUCTOR TEMPERATURE, 70 DEG. C.

Material	Per Cent Conductivity	Relative Current-carrying Capacity
Copper and Copper Alloys	100	1.00
	95	0.98
	90	0.96
	85	0.94
	80	0.91
	75	0.88
	70	0.86
	65	0.83
	60	0.80
	55	0.77
	50	0.74
Aluminum	61	0.78
	55	0.74
	50	0.71

EXAMPLES OF THE CALCULATION OF CURRENT-CARRYING CAPACITY AND TEMPERATURE RISE

The following examples illustrate the practical application of the data given in this article:

Example 1: To find the current-carrying capacity of a tube 1.315 in. outside diameter and 1.022 in. inside diameter of 85 per cent conductivity copper for 30-deg. C. rise outdoors at 60 cycles.

The outside diameter is exactly equal to that of the one-inch extra heavy pipe size given in Table VII, Item 4, which is rated at 1010 amp. for outdoor service. Allowance for the difference of copper cross section is made as follows:

The cross-section of the one-inch tube specified in Table VII is

$$a = 1315^2 - 951^2 = 1{,}730{,}000 - 905{,}000 = 825{,}000 \text{ cir. mils}$$

The cross-section of the tube in this example is

$$a_1 = 1315^2 - 1022^2 = 1{,}730{,}000 - 1{,}045{,}000 = 685{,}000 \text{ cir. mils}$$

The skin effect ratio is practically 1.0 at 60 cycles for both tubes. Thus, according to Equation (13)

$$q = \sqrt{\frac{ka_1}{k_1a}} = \sqrt{\frac{685{,}000}{825{,}000}} = 0.91$$

The outdoor current rating for the tube of cross section a_1 for 100 per cent conductivity copper is

$$0.91 \times 1010 = 920 \text{ amp.}$$

The relative current-carrying capacity for 85 per cent conductivity copper from Table VIII is 0.94.

Thus the current-carrying capacity of the tube specified is

$$0.94 \times 920 = 865 \text{ amp.}$$

Example 2: To find the current-carrying capacity of a tube ¾ in. outside diameter and ½ in. inside diameter of 100 per cent conductivity copper for 30-deg. C. rise outdoors at 60 cycles.

Substitute the following numerical values in Formula (12):

$C = 3350$ from Fig. 16, for outdoor service
$d = 0.75$ in.
$d_1 = 0.50$ in.
$r = 12.59$ ohms per mil-foot at 70-deg. C.
$k = 1.0$

Thus

$$I = 3350\sqrt{\frac{0.75^2 - 0.50^2}{1 \times 12.59}} = 528 \text{ amp.}$$

where I is the current-carrying capacity of the tube specified.

Example 3: To find the current carrying capacity of a 1,500,000 cir.-mil bare cable, 98 per cent conductivity copper, for 30-deg. C. rise outdoors at 60 cycles.

The outside diameter of the cable is 1.412 in. and the resistance(9) is 0.00719 ohm per 1000 ft. at 25-deg. C.

Substitute the following numerical values in Formula (10):

$R_1 = 0.00719 \times 10^3\,[1 + 0.00385\,(70 - 25)]$
$= 8.43$ microhms per ft. (at 70-deg. C.)
$k = 1.14$ (see references(9))
$C = 4030$ (from Fig. 16, for outdoor service)

Thus

$$I = \frac{4030}{\sqrt{1.14 \times 8.43}} = 1300 \text{ amp.}$$

The relative current-carrying capacity for 98 per cent conductivity copper is 0.99, from Table VIII.

Thus the current-carrying capacity of the cable specified is

$$0.99 \times 1300 = 1290 \text{ amp.}$$

Example 4: To find the current-carrying capacity at 60 cycles of the 1,500,000 cir.-mil cable specified in Example 3 for 50-deg. C. rise outdoors at high elevation where the wind velocity is six feet per second (minimum), the air temperature to be taken as 40 deg. C.

The procedure is to calculate separately the components of the heat dissipated due to convection and radiation and add them to get the total heat dissipated. Then substitute in Equation (1) and solve for the current.

The following numerical values are used in the formulas:

$d = 1.412$ in. (see Example 3)
$p = 1.0$ (for atmospheric pressure)
$v = 6.0$ ft. per sec.
$\Delta t = 50$ deg. C.
$T = 90+273 = 363$ deg. K.
$T_o = 40+273 = 313$ deg. K.
$T_a = 338$ deg. K. (average of T and T_o)
$E = 0.5$ (for copper in service)

By Formula (9)

$$w_c = \frac{0.0128 \times \sqrt{6} \times 50}{\sqrt{1.412} \times 338^{0.123}} = 0.642 \text{ watts per sq. in.}$$

By Formula (7)

$$w_r = 36.8 \times 0.5 \left[\left(\frac{363}{1000}\right)^4 - \left(\frac{313}{1000}\right)^4\right] = 0.144 \text{ watts per sq. in.}$$

Hence $w = 0.642+0.144 = 0.786$ watts per sq. in.

The envelope surface per foot of cable is

$$A = \pi \times 1.412 \times 12 = 53.4 \text{ sq. in.}$$

The heat dissipated per foot of cable is

$$wA = 0.786 \times 53.4 = 42.0 \text{ watts}$$

The 60-cycle resistance per foot of cable at 90 deg. C. is

$$kR = 1.14 \times \frac{7.19}{0.98} \times 10^{-6}[1+0.00377\,(90-25)]$$

$$kR = 10.4 \times 10^{-6} \text{ ohms}$$

The electrical heat per foot of cable is

$$I^2 \times 10.4 \times 10^{-6} \text{ watts}$$

Substituting in Equation (1) and solving for I

$$I = \sqrt{\frac{42.0}{10.4}} \times 10^3 = 2010 \text{ amp.}$$

where I is the required current-carrying capacity.

Example 5: To find the temperature rise of a No. 0000 A.W.G. 100 per cent conductivity copper wire carrying 480 amp. in still air at 25 deg. C.

The procedure is to assume several values of temperature rise, as 60, 70, 80 deg. C. etc., and calculate the heat dissipated as in *Example 4*. Plot the values of heat dissipated against temperature rise and on the same sheet plot the electrical heat supplied. The point of intersection of these curves satisfies Equation (1) and therefore shows the temperature rise for the conditions specified.

For illustration, the calculation of the heat dissipated when the temperature rise is 70 deg. C. is shown below:

$\Delta t = 70$ deg. C.
$T = 368$ deg. K.
$T_o = 298$ deg. K.
$T_a = 333$ deg. K.
$p = 1$ (for atmospheric pressure)
$d = 0.46$ in.
$E = 0.5$

Then by Formula (6)

$$w_c = \frac{17.5 \times 10^{-6}\ 333^{0.754} \times 70}{0.46 \log_e \left[\frac{0.0031 \times 333^{0.947}}{0.46^{0.81} \times 70^{0.27}} + 1\right]} = 0.570 \text{ watts per sq. in.}$$

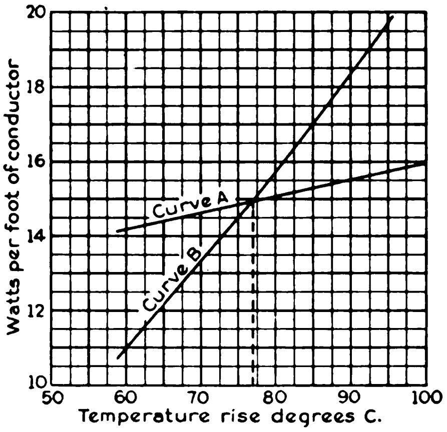


Fig. 17. Curves of Watts *vs.* Temperature Rise for the No. 0000 A.W.G. Conductor in Example 5

Curve A: Electrical heating at 480 amp.
Curve B: Heat dissipated by convection and radiation in still air.

and by Formula (7)

$$w_r = 36.8 \times 0.5 \left[\left(\frac{368}{1000}\right)^4 - \left(\frac{298}{1000}\right)^4\right] = 0.191 \text{ watts per sq. in.}$$

Thus $w = 0.570+0.191 = 0.761$ watts per sq. in.

The heat dissipated per foot of conductor is

$$wA = 0.761 \times \pi \times 0.46 \times 12 = 13.3 \text{ watts.}$$

The values of watts dissipated per foot of conductor have been plotted on Fig. 17. The values of electrical heat per foot have been plotted on the same curve sheet. For instance at 70-deg. C. rise (conductor temperature, 95 deg. C.) the I^2R loss is as follows: The resistance per foot of conductor at 20 deg. C. is 49.0×10^{-6} ohms, and at 95 deg. C. the resistance is

$$R = 49.0 \times 10^{-6}[1+0.00393\,(95-20)]$$
$$= 63.5 \times 10^{-6} \text{ ohms}$$

The electrical heat per foot of conductor is

$$I^2R = 480^2 \times 63.5 \times 10^{-6} = 14.6 \text{ watts}$$

The curves on Fig. 17 intersect at a point corresponding to 77-deg. C. temperature rise. Since this point satisfies Equation (1) the temperature rise is 77 deg. C. for the conditions specified.

CONCLUSIONS

(1). This article gives current ratings for bare conductors in outdoor installations under specified wind conditions, and for indoor installations, for 30-deg. C. rise in an air temperature of 40 deg. C. for conductor sizes ranging from 0.3 to 4.5-in. diameter. The ratings are based on test data and are in agreement with independent calculations.

(2). In order to establish ratings for outdoor conductors data on wind velocities were studied and analyzed and it was found that in partly sheltered installations, for instance close to a building (but not sheltered by structures on more than two sides or completely surrounded by buildings), sustained wind velocities lower than two feet per second are not to be expected more than five per cent of the time during the summer season. The simultaneous occurrence of high air temperature and low wind velocity (below two feet per second) is of course still less frequent, so that the chance of overheating conductors rated on the basis of a wind velocity of two feet per second in partly sheltered locations is practically negligible.

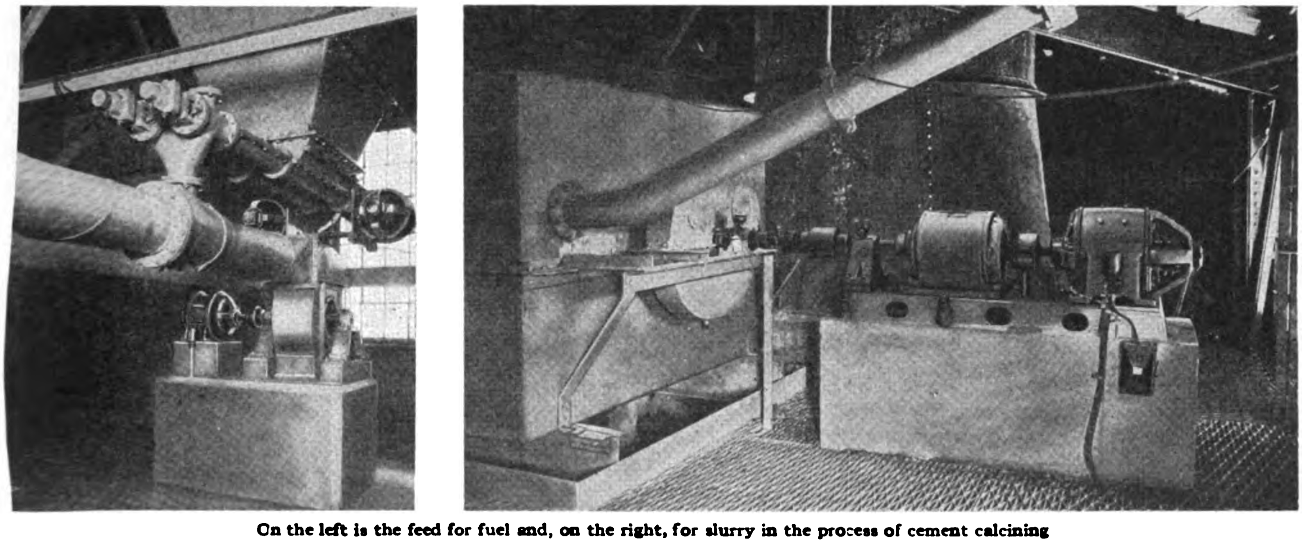
(3). The effect of the summer sun on the temperature rise of the conductors was also studied by means of tests, and it was found that the bright sunshine early in September added about two to three deg. C. to the temperature rise when the current was such as to heat the conductor to 30 deg. C. above the air. In view of the conservative value of wind velocity chosen, outdoor conductors in partly sheltered locations may be rated without serious error on the basis of an air velocity of two feet per second without making separate allowance for the effect of the sun. Test data confirming this point are given.

(4). The current ratings for 30-deg. C. rise for outdoor conductors for wind velocities of two feet per second are from 14 to 35 per cent greater than those for indoor conductors, the 14 per cent value applying to the largest conductor considered (4.5-in. diameter), the 35 per cent value applying to the smallest conductor considered (0.3-in. diameter). For more fully sheltered locations, of course, lower ratings have to be used.

(5). Formulas, based on previous researches, are given in simple form for the calculation of temperature rise and of current-carrying capacity for cylindrical conductors.

(6). The rate of heat dissipation per unit area (*i.e.*, watts per sq. in. dissipated) from conductors at a given temperature rise is not the same for conductors of different sizes but diminishes with increasing conductor diameter because of the diminishing rate of heat convection. While this point is not new, having been brought out in previous literature, current ratings based on a constant rate of heat dissipation regardless of the conductor size are still being used. The ratings given here take this factor into account.

Electric Motors in the Cement Industry



On the left is the feed for fuel and, on the right, for slurry in the process of cement calcining

Speed, Comfort, and Safety With a New Multipoint Control

By C. J. AXTELL and R. H. SJOBERG

Transportation Engineering Department, General Electric Company

Street cars nowadays encounter such traffic difficulties that they appear to have lost much of their older attractiveness as the preferred means of transportation. In this article a newly developed means furnishing at least a partial solution is described by the authors, who last year delivered separate papers at conventions of the Central Electric Railway Master Mechanics Association and the New York State Electric Railway Association.—Editor

An outstanding problem confronting the executives of our street railway systems is that of, first, maintaining the patronage of the present car riders and second, increasing riding and attracting those who may now be using other means of transportation.

The private automobile is the chief competitor of the street car, since the number of automobiles in use in the United States is such that there is one for almost every family. The private car, while undoubtedly a great convenience for the owner in enabling him to go when and where he pleases, is causing such congestion of the streets, by reason of the great number in use, that it is becoming increasingly difficult to thus navigate traffic in our cities. The parking problem too, in congested centers, has become so acute that it is often more convenient to ride on the street car than to hunt a vacant spot where an automobile can be parked. The means, then, of regaining the lost car riders lies in the providing of a fast, frequent, and comfortable street-car service.

Several factors enter into consideration in obtaining a high schedule speed of street cars, some of which are: introducing the skip or alternate stop, increasing the free running speed of the car, reducing the time of unloading and loading passengers, increasing the rate of acceleration, and increasing the rate of braking.

The comfort of the car depends upon three principal factors: first, that of having a clean and attractive car with restful seats; second, that of having the car of good riding qualities; and third, having the electrical equipment and brakes so designed that the starting and stopping of the car is smooth and without jerks or quick changes in the motion of the car.

The question of rapid acceleration deserves considerable thought for two reasons. The first is its effect on schedule speed and cutting down the time required to get from one point to another; and the second is the psychological effect upon the passenger of having the car start promptly and rapidly.

A considerable amount of time is lost on the present cars by their slow acceleration. A car starting from a near-side stop frequently has to compete for the right of way across an intersection with a line of private automobiles also awaiting an opening of the traffic on the cross street. In such cases the present street car comes out a poor second in the race, because the automobiles can accelerate much faster than the one and one-half miles per hour per second for which the cars are designed. The result is that all of the automobiles start, pass the street car, and wedge into the line of traffic immediately ahead, necessitating the motorman giving way and taking his place at the rear of the procession instead of at the head. This condition also has its effect upon the passenger who is not content to sit complacently in his seat and watch others in automobiles pass him at every street intersection.

A few figures may be interesting in showing the difference that an increase in acceleration from 1½ mi. per hr. per sec. to 3 mi. per hr. per sec. will make. In four seconds a car accelerating at 3 mi. per hr. per sec. will have traveled 34 ft. while at 1½ mi. per hr. per sec. it would have covered only 17 ft. In five seconds the first car would have gone 54 ft. and the second car only 27 ft. Now analyze for a moment the action of a motorist who starts at the same instant from a point alongside the street car. With a good car he may be able to attain an accelerating rate of 3 mi. per hr. per sec. He must, however, shift gears at least once and perhaps twice in that brief time. The result is that the street car not only has a clear track ahead but it maintains this advantage, for the motorist is unable to pass. This is not a theoretical advantage but an actual one, as has been demonstrated repeatedly on cars equipped to give this high-class service.

In recognition of this, there has come the need for a control to provide smooth acceleration at rates of 3 mi. per hr. per sec. or greater. Such is now manufactured as an automatic multipoint control(1) which is a composite of the magnetic and the pneumatic-cam-operated types of control, and is designed especially for street cars and trolley buses. Because it has 18 points, which is twice the ordinary number of control points, this type of control is capable of smooth acceleration at rates in excess of 3 mi. per hr. per sec. Its flexibility and automatic feature really make foot control practical, although it is as well adapted for hand operation. Fig. 1 shows the motor current increments for each point of the controller for both the platform-type and the automatic 18-point control at the same rate of acceleration and with the same weight of car. Since the changes in motor currents are small for the composite control, the motors can be operated more closely to the slipping point of the wheels. The acceleration is automatic in its action so that the same high smooth rate is always obtained.

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(1) Identified by the trade designation "PCM."

However, even with its 18 automatic accelerating steps, pneumatic-magnetic control has at the same time all the flexibility of a non-automatic type, as the operator can arrest any further advance of the motor controller and hold it in any notch in which it may be at the time.

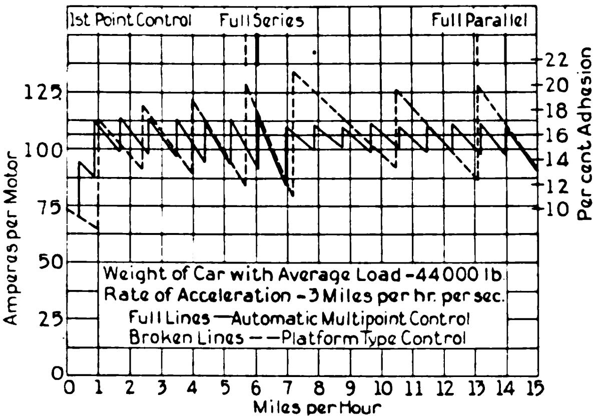


Fig. 1. Chart Showing the Fast, Smooth Acceleration Secured Through Use of Multipoint Control

Of equal importance with faster acceleration are higher rates of braking; for if cars are to be run faster it must be possible to brake them more rapidly. By the use of quick application and release valves, braking rates of 3 mi. per hr. per sec. are made practical. The addition of magnetic track brakes to regular air brakes would increase the maximum braking rate by at least 25 per cent and would assist in decreasing the running time, particularly in congested sections. The use of these brakes may be limited to emergency or optional applications on the operator's part. On the present streets the rails are often slippery from grease and the residue left by the rubber tires of automobiles. Since the effectiveness of track brakes is not so dependent upon rail conditions as wheel brakes, they are most valuable on slippery rails. Track brakes would give the operator confidence in his ability to stop and he would maintain less distance to the rear of traffic ahead of him. By thus keeping the gap closed he would prevent automobiles from cutting in ahead of him and slowing him down. The additional braking would be valuable in case of emergency and in preventing accidents, especially on slippery rails. This is an additional safety feature which should materially add to the dependability of the street car.

In city service the most economical way to secure increased schedules is by means of faster rates of acceleration and braking. Fig. 2 shows the effect of acceleration on schedule and energy consumption in an average service of seven stops per mile while maintaining a constant rate of 2.5 mi. per hr. per sec. braking. With the same motor equipment, the schedule may be increased 4.5 per cent for the same energy consumption because of the less loss in rheostats if the accelerating rate as permitted by the motors could be increased from 2.0 mi. per hr. per sec. to 3 mi. per hr. per sec. Hence it is advantageous to have a control which allows the operator to use the maximum rate of acceleration permitted by motor capacity. Fig. 3 shows the effect of braking on schedules and energy consumption in an average service of seven stops per mile while maintaining a constant rate of 2.5 mi. per hr. per sec. acceleration. By going from 2.0 mi. per hr. per sec. to 3.0 mi. per hr. per sec. braking the schedule may be increased 5.3 per cent for a 4.8 per cent increase in energy consumption. Service may sometimes be speeded up by the use of a large pinion with an accompanying increase in energy consumption. Although faster schedules generally require more power, the most economical and practical speeding up of city schedules is accomplished by means of higher rates of acceleration and braking.

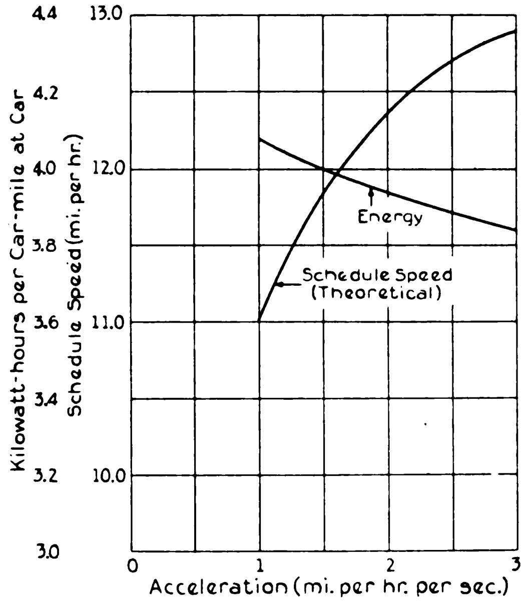


Fig. 2. Graphical Study of Schedule Speed and Energy Consumption for Various Rates of Acceleration

Constant braking rate of 2.5 mi. per hr. per sec., seven stops of 8 sec. average duration per mile; average voltage, 550, car weight with load, 40,000 lb.; four 35-hp. 600-volt motors.

Cars of weights which were a short time ago equipped with four 25-hp. motors are now being equipped with four 35-hp. motors; while cars of weights formerly equipped with four 35-hp. motors are now being equipped with four 50-hp. motors. This is a step in the right direction, because it is believed that in the average city service the motor capacity should be sufficient to permit accelerating rates of at least 3 mi. per hr. per sec. and a free running speed of at least 30 mi. per hr. For a given weight of car, the maximum rate of acceleration depends upon the motor capacity, providing the adhesion at the rails is sufficient to prevent slipping of the wheels. However, the passenger comfort must be considered during acceleration and hence, regardless of motor capacity, the rate of acceleration is generally limited to 2.0 mi. per hr. per sec. by the ordinary types of control which have 8 to 9 steps.

Aside from equipment there are several other important factors which determine schedules, *viz.*, stops per mile, duration of stop, and voltage. For example, if the stops per mile could be decreased from eight to six an increase in schedule speed of 15 per cent would be possible. The effect of stops per mile on schedules is shown in Fig. 4. There is a limit to the decrease in stops; for if the distance between stops is too great, the patrons will not walk to the car stop and the number of riders may be decreased. However, the importance of this factor warrants a closer study of the number of stops per mile on existing lines. Slowdowns and running times in congested sections may also be decreased by "no parking" ordinances.

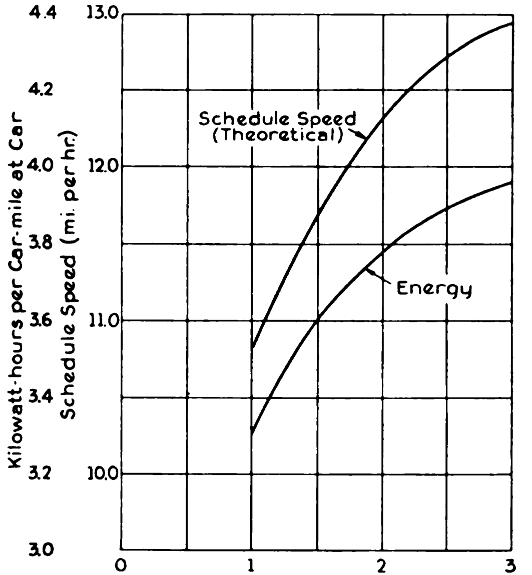


Fig. 3. Graphical Study of Schedule Speed and Energy Consumption for Various Rates of Braking Under Conditions Corresponding to Fig. 2

The effect of the duration of stop on schedule is also shown in Fig. 4. At six stops per mile a decrease in average duration of stop from 10 to 8 sec. would make possible a 5 per cent increase in schedule. The modern car with its low car floors, treadle doors, wide, easy exits, and its flexible and easily accessible control has helped materially in decreasing the duration of stops. A number of operating companies are considering cars equipped with foot-operated control and air brakes which, in the case of the one-man car, gives the operator more freedom of his hands in making change and handling transfers.

Good voltage is of prime importance on grades and non-congested sections where free running speeds are possible.

To show the economies possible with new cars there is here taken as an example the average service typical of a city of 150,000, which is as follows:

Round trip distance	8.0 mi.
Headway	6.0 min.
Average voltage	550
Stops per mile	7.0
Average duration of stop	10.0 sec.
Average passenger load	4000 lb.

This service is now being rendered by one-man cars weighing about 45,000 lb. equipped with four 40-hp., 500-volt motors and 33-in. wheels and having a free running speed of approximately 26 mi. per hr. on 550 volts. In such service this equipment makes possible a schedule speed of 9.9 mi. per hr. (not including layover) with 1.75 mi. per hr. per sec. acceleration and braking thus requiring a round trip time of 54 min. including 5.5 min. layover with nine cars on the line.

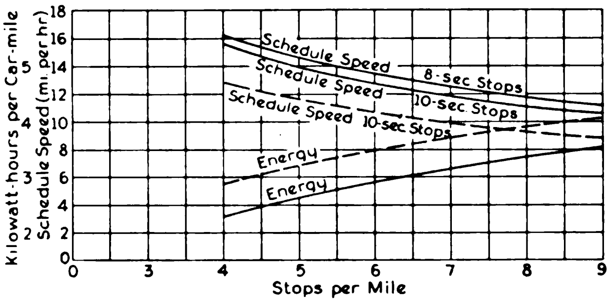


Fig. 4. Comparative Schedules and Energy Consumption of Different Cars Under Different Conditions of Acceleration and Braking

Full lines: 30,000-lb. car; four 35-hp. 600-volt motors; 26-in. wheels; 3 mi. per hr. per sec. acceleration and braking.

Broken lines: 45,000-lb. car; four 40-hp. 500-volt motors; 33-in. wheels; 1.75 mi. per hr. per sec. acceleration and braking.

In both cases, average voltage = 550; average passenger load = 4000 lb.

A new car weighing approximately 30,000 lb. and equipped with four 35-hp. motors and 26-in. wheels, multipoint automatic control, treadle doors, quick release and application brake valves and track brakes would be capable of an accelerating and braking rate of at least 3.0 mi. per hr. per sec. and would have a free running speed of approximately 31.5 mi. per hr. on 550 volts. With its low car floors and wide easy exits, this car would cut down the duration of stop to about eight seconds and would make a schedule speed of 12.6 mi. per hr. (not including layover) or an increase of about 27 per cent with 16 per cent less power consumption. This car would have a round trip running time of 42.0 min. including 4.0 min. layover, thus requiring seven cars on the line.

The economies which can be effected by new cars are shown on the summary sheet (Table I). On the basis of 18-hr. service the operating costs of the typical line with the new light-weight cars will amount to $62,600 per year as compared to $85,700 for the present service, thus showing a saving of $23,100. The proposed schedule requires seven new cars which with one spare makes a total of eight and involves an investment of approximately $136,000. This comparison shows a 17 per cent return on the investment. No allowance in these figures has been made for increase in revenue which, obviously, must be expected if the investment is to be made, and, allowing for only 5 per cent increase for the new cars and faster schedules, the increase in revenue would be $12,000 per year. The combined increase in revenue with the saving in operating costs totals $35,100 which is equivalent to 25.8 per cent return on the proposed investment, and the new cars should pay for themselves in four years.

TABLE I

SUMMARY SHEET

	Present	Proposed
Schedule speed (incl. layovers) mi. per hr.	8.9	11.4
No. of cars in operation	9	7
Power (kw-hr. per car-mi. at car) with 7 stops per mile	3.7	3.1
Annual car-miles	525,000	525,000
Annual car-hours	59,100	46,000
Annual operating costs:		
Heavy equipt. at 4¢ per car-mi.	$21,000	
Lightweight equipt. at 2¢ per car-mi		$10,500
Power at 1.5¢ per kw-hr. at car.	$29,200	$24,500
Platform expense at 60¢ per hour	$35,500	$27,600
	$85,700	$62,600
Saving over present		$23,100
No. cars required incl. one spare		8
Estimated investment at $17,000 per car		$136,000
Return on investment due to savings		17%
Present revenue assumed as 45¢ per car-mi.	$236,000	
Revenue with 5% increase due to new cars and increased schedules		$248,000
Net saving and increased revenue		$35,100
Gross return expected on investment		25.8%

Since it is hardly economical to use the new cars in tripper service, speeding up the best of the present cars either by some such means as changing the gear ratio or shunting the fields is suggested, since it is seldom practical to speed up these cars by faster rates of acceleration. Although these faster schedules would increase the duty on the tripper car equipments it would only be for short periods; and since the annual car mileage would be low, the annual cost of maintenance would be comparatively small.

In conclusion, it seems particularly appropriate to point out more specifically some of the developments which have been made to accomplish certain of the needed improvements in service. These have to do with the functions of the control equipment. The control should govern the motors in such a manner that the acceleration is smooth, comfortable, and rapid, at the same time operating with as little attention from the motorman as possible. Another requisite is to make the control so that it will protect the motors from any abuse and thus reduce the maintenance to a minimum.

The new automatic type of control (Fig. 5) has been designed and built to provide comfortable, rapid acceleration with the least effort on the part of the motorman. This control, as already pointed out, is a combination of two types, contactor control and the pneumatic-cam operated control. It is termed a multipoint control inasmuch as it has twice the number of points usually employed for accelerating. The control is made with nine points for series acceleration and nine for parallel, thus providing such small increases in motor current at each step that the effect of notching up the control cannot be felt by the passenger even when accelerating at higher than 3 mi. per hr. per sec. On the first point of the control a rate of about 2 mi. per hr. per sec. is provided to make a comfortable start. The control then rapidly notches up to the full accelerating rate, which is automatically maintained until the motors are in the full parallel connection. The consequence of this is that the car starts smoothly and gives the impression of gliding away rather than accelerating in a series of jerks. This effort is very noticeable and usually elicits particularly favorable comment from one riding for the first time on a car equipped with such a control.

Because of the large number of points on the control and the resultant small increase in the current at each notch, the average current can be held much nearer to the value at the slipping point of the wheels than when the current peaks are much higher, as would be the case when attempting to attain a high rate of acceleration with a control having fewer points.

In the new control the main motor connections are made by four magnetic contactors, *viz.*, one line breaker, one series contactor, and two parallel contactors. These are each provided with a powerful magnetic blowout. The line breaker has also a quick-acting overload relay so arranged that any overload or short-circuit current will react positively on the armature of the contactor to give it a sharp blow to open the circuit with unusual rapidity. The resistors in the main motor circuit are cut out by means of eleven small spring-closed cam-opened contactors. These are arranged on opposite sides of a cam shaft which shaft is turned forward and backward by a small air engine. The eleven contactors have therefore but one prime mover to operate the entire group.

These resistor contactors are connected so that their only duty is to short circuit the various resistor sections; consequently they require no blowouts, because they never break an arc. From a maintenance standpoint this is very desirable as there is no burning of these tips whatever and the exposed arrangement permits them to be inspected at a glance.

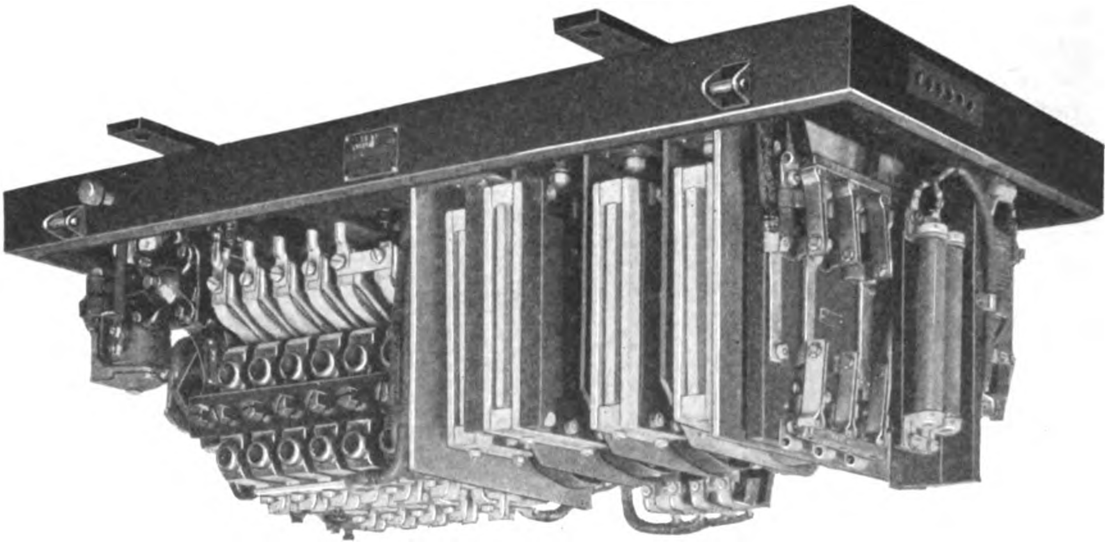


Fig. 5. Main Motor Control Unit

By a unique circuit combination the cam-operated contactors are closed in succession for the series connection of the motors by turning the cam shaft in the forward direction. When the full series connection is obtained, the two parallel contactors are closed and the series contactor opened which gives the first point in parallel. The parallel acceleration is obtained by turning the cam shaft backward to the initial position, the resistor contactors then closing in the reverse order. In the full parallel position the cam shaft is in the same position as at the start. In shutting off the power the line breaker and parallel contactors open immediately. The control is then ready to re-apply the power to the motors without any delay. The control being automatic in its action the power can only be re-applied on the first series point, after which the contactors will again notch up automatically.

The direction of car movement is governed by the reverser, which on a double-end equipment is a small remotely-operated reverser mounted underneath the car to reduce the main wiring to a minimum. For a single-end car, a hand-operated reverser can be employed without greatly increasing the complications in the wiring. This can be placed in a cabinet conveniently located within reach of the operator. Since all of the power circuits are handled by the motor controller, which may be located either underneath the car or in a cabinet provided for the purpose, it is apparent that the circuits handled by the operator to govern the car are of small current rating, the control current required being about one-half that required for lighting the car. The master controller in the cab is therefore small.

One type of master controller is operated by hand (Fig. 6) in the manner of a platform type controller; another type (Fig. 7) provides this device in a box recessed in the floor and operated by the motorman's foot. The control being automatic in its action, there are only four positions on the master controller:

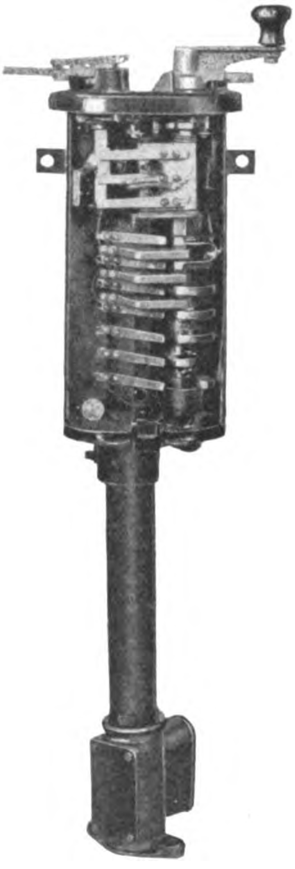


Fig. 6. Master Control Unit for Manual Operation

(1). Off
(2). First series or switching
(3). Full series
(4). Full parallel

By turning the master controller handle to any one of these positions, or by depressing the foot controller, if used, to the same position, the motor controller will automatically notch up to the position indicated by the master controller without any further attention from the operator who may be at the same time making change or issuing transfers, if it is a one-man car.

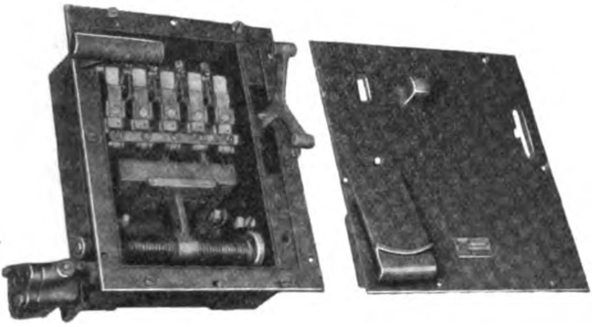


Fig. 7. Master Control Unit for Pedal Operation

The contacts in the foot controller are cam-operated and magnetically held, so that all contacts have a quick make and break. This prevents any possibility of the operator holding between points of the foot controller and burning the contacts.

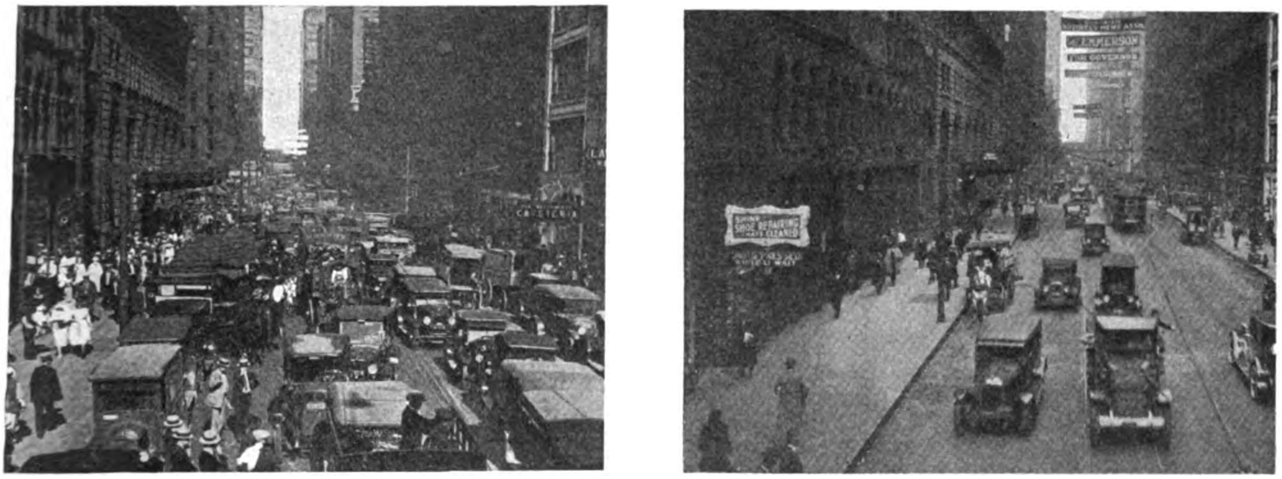
While automatic in operation, this control has at the same time all the flexibility of a non-automatic type since by notching back the master controller one point the operator can arrest any further advance of the motor controller and hold it in any notch in which it may be at the time.

Unlike previous automatic controls this new control does not depend on the current in the motor to notch from one point to the next. It normally notches on time; however, if the motor currents would exceed the safe commutating limits the accelerating relay protects the motors by increasing the time interval between points. In order to provide means of operating under such conditions of track that the full accelerating rate would slip the wheels, a second and lower rate can be obtained by turning a small snap switch located conveniently near the operator. The entire motor controller enclosed in a box for mounting underneath the car is very small and weighs only 435 lb. This makes a control equipment especially adapted for the newer designs of light-weight cars. On double-end equipments the only apparatus to be duplicated is the master controller.

Quite a number of these equipments are in actual service. One hundred equipments recently manufactured for the Surface Lines in Chicago are for use on new cars equipped with four 50-hp. motors.

This type of control is equally well adapted for use on trolley buses where the same conditions exist as on rail cars. On trolley buses the foot-operated master controller is necessarily used. A hand-operated reverser is also applied as the equipment is for single-end operation.

The Cause and Result of a Municipal Experiment



Madison Street, in the busiest section of Chicago, before and after a traffic signal light system and "No Parking" regulations were applied. Street-car schedules speeded up; more automobile traffic ensued; and business in the section increased

Nomograms

A Summary of Their Theory and a Description of Their Use for Complex Hyperbolic Functions and for Conversion Between Rectangular and Polar Coördinates

By **JOERGEN RYBNER**

Formerly of Research Laboratory, General Electric Company

GRAPHICAL methods are of very great importance in science and engineering. Their significance has increased especially after the fundamental work on this subject by Professor M. d'Ocagne of Paris, who has developed it into a new branch of science, called by him Nomography (Greek: νόμος, law; γράφειν, write, draw, describe). The purpose of nomography is partly to illustrate the properties of mathematical functions, partly to facilitate numerical computations.

> *That problems in two variables are solved easily by the slide rule is familiar to all engineers. The facility with which problems in three or more variables can be solved by suitable nomograms is not so well known. For this reason we have induced Mr. Rybner to translate and amplify for the* REVIEW *his excellent article which appeared in "Ingenioeren," the official journal of the Danish Institute of Engineers.—*EDITOR

In both of these respects, the ordinary graphs of functions of *two* variables, $F(x, y) = 0$ are very satisfactory: In this case, a curve is drawn on cross-sectional paper through all points whose coördinates (x, y) satisfy the given equation.

But in case of three or more variables, difficulties arise. There are two general types of charts for such functions, *viz.:* families of curves in some coördinate system, and alignment charts. The first-mentioned type of charts is obtained by simple extension of the principles used where only two variables are involved. If the given equation is $F(x, y, z) = 0$, certain fixed values can be given to z, and in each case the equation is reduced to an equation in only two variables x and y, *viz.*, $F(x, y, z_0) = 0$. Therefore, a curve can be plotted for each desired value of z, so that we get a family of z curves, between which we can interpolate, if necessary. Generalizing to any coördinate system for x and y we can say that the three families of curves, $x =$ const., $y =$ const., and $z =$ const., assign to every point of the graph three coördinates x, y, z, so that every one of these sets of values satisfies the equation $F(x, y, z) = 0$.

Example 1: A simple example of graphs of this kind is a multiplication chart. In this case the given function is $xy - z = 0$. We use x as abscissa and y as ordinate in an oblique coördinate system. The curves $z =$ const. are rectangular hyperbolas with the coördinate axes as asymptotes (Fig. 1). If for instance $x = 7.8$ and $y = 4.7$ (the point is marked with a little circle in the chart), it is found by interpolation between the hyperbolas $z = 35$ and $z = 40$ that $z = xy = 37$.

This system of curve families or points with several coördinates can be expanded in different ways to more than three variables, for instance as shown in Fig. 2. Here, the left-hand system of curves represents an equation $F(x, y, z) = 0$ and the right-hand system an equation $F(z, u, v) = 0$ so that the z curves connect the two systems. If now $x = 2$, $y = 10$, this corresponds to $z = 9.2$; if furthermore $u = 40$, this gives, together with $z = 9.2$, $v = 6.4$; and v is in this way determined as a function of the three variables x, y, and u.

Graphs of this type (*i.e.*, like Fig. 1 or Fig. 2) often give a good illustration of mathematical laws. But they are not very well suited for numerical calculations because of the double interpolation which is necessary between the two families of curves; and the curves can not be drawn very close together, partly because of the amount of work involved in the determination and drawing of them, partly because it would complicate the graph and disturb its perspicuity.

The other general type of graph is the so-called alignment chart which was introduced by d'Ocagne. This applies, in its simple form, to functions of three variables, $F(x, y, z) = 0$, and the principle is that there are drawn three curves with such scales for the variables that a straight line cuts the three scales in values of x, y, and z satisfying the equation. If now two of the quantities are given, a straight line through their appropriate points will cut the third scale in the corresponding value of this variable. Fig. 3 illustrates the principle, showing x, y, and z scales, all curved; the dotted line connects the values $x = 17.0$ and $y = 0.440$ and determines the corresponding value $z = 1.66$. Of course, no line is actually drawn in practice but a movable line of some sort is used, for instance the edge of a rule; but a fine scratch on the bottom side of a celluloid rule is preferable as it allows a better interpolation.

We will now mention some different types of alignment charts, beginning with the simpler types and ending with the most general case.

Case I: Three Parallel Lines

The simplest case is that of three parallel scales, as A, B, and C in Fig. 4. Suppose that the graduations are $\alpha = l_1 \cdot f(x)$; $\beta = l_2 \cdot g(y)$; $\gamma = l_3 \cdot h(z)$. It is now seen from the diagram that when the end points of α, β, and γ are in a straight line they are related as follows:

$$\beta = \frac{\delta_2}{\delta_1+\delta_2}\alpha + \frac{\delta_1}{\delta_1+\delta_2}\gamma \qquad (1)$$

Inserting the values of α, β, and γ, we get:

$$g(y) = \left(\frac{1}{1+\frac{\delta_1}{\delta_2}}\cdot\frac{l_1}{l_2}\right)\cdot f(x) + \left(\frac{1}{1+\frac{\delta_2}{\delta_1}}\cdot\frac{l_3}{l_2}\right)\cdot h(z) \qquad (2)$$

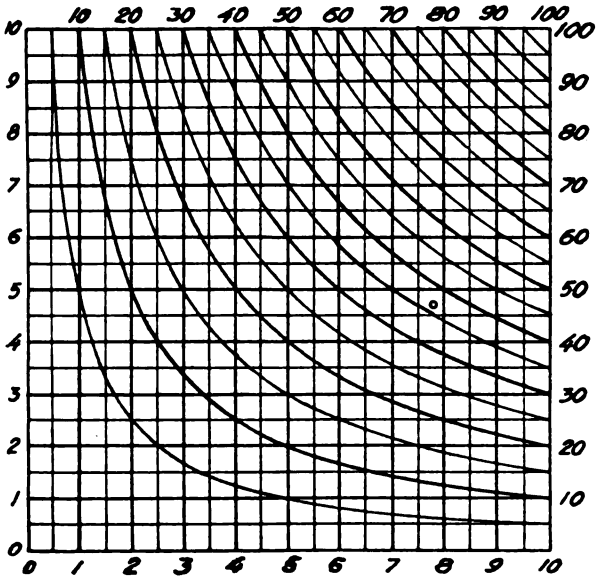


Fig. 1. A Multiplication Chart

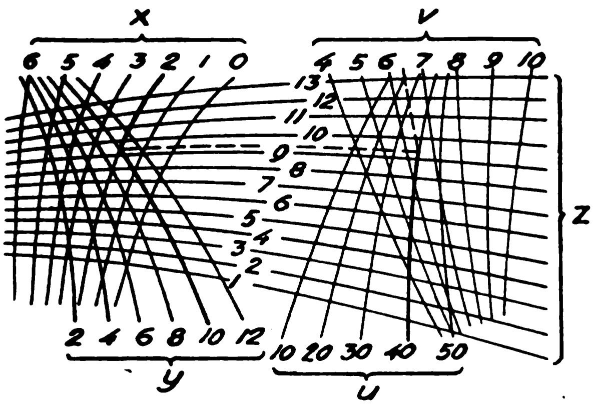


Fig. 2. Nomograms Involving Families of Curves Having Four Variables

This relation holds for any position of the dotted line in Fig. 4 so that we have here a nomogram for an equation of the form:

$$g(y) = a\cdot f(x) + b\cdot h(z) \qquad \text{I}$$

On the other hand, it is seen that any equation of the type I can be represented in a graph like Fig. 4 when we plot the parallel scales $\alpha = l_1\cdot f(x)$, $\beta = l_2\cdot g(y)$, $\gamma = l_3\cdot h(z)$ and chose the constants l_1, l_2, l_3, δ_1, and δ_2 such that the coefficients of $f(x)$ and $h(z)$ are the same in Equations (1) and (2). Examples of this kind are:

$$y = ax + bz;\ y^2 = ax^2 + bz^2;\ \log y = a\log x + b\log z,$$
$$i.e., y = x^a\cdot z^b$$

Example 2: We will consider the same problem as in Example 1, *viz.*, simple multiplication, $y = x\cdot z$ or $\log y = \log x + \log z$. Comparing the latter equation with (2) we see that $g(y) = \log y$, $f(x) = \log x$, and $h(z) = \log z$, so that all scales are logarithmic. If we choose $\delta_1 = \delta_2$, we must make $l_1 = l_3 = 2l_2$ in order to obtain the coefficients unity of both $f(x)$ and $h(z)$. This gives a chart like Fig. 5. The y scale has two decades in the same length as one decade of the x or z scale. The dotted line shows how $x = 7.8$ and $y = 4.7$ gives $z = x\cdot y = 36.7$.

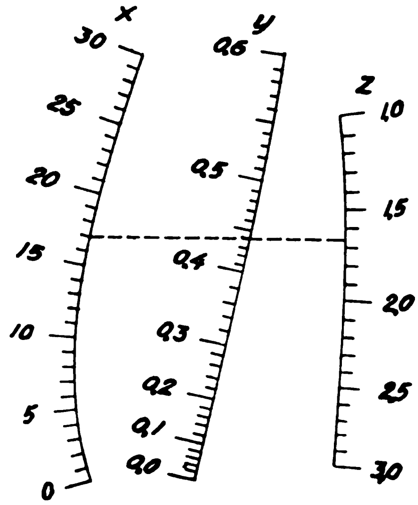


Fig. 3. Illustrative Diagram Showing Principle of Alignment Charts

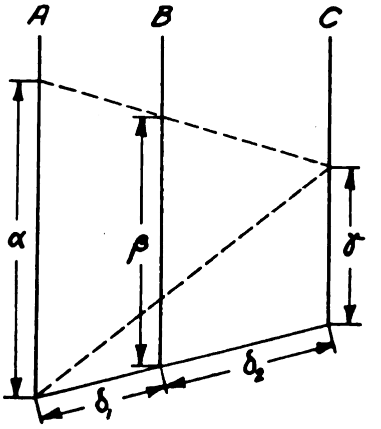


Fig. 4. Diagram Illustrating Case I: Three Parallel Lines

The principles of this chart can be understood directly. As we have chosen $\delta_1 = \delta_2$ (Fig. 4), we get $\beta = \frac{1}{2}(\alpha + \gamma)$. But the β graduation is in half the scale of the α and γ graduations, hence the β reading must correspond to $\alpha + \gamma$, or the log y to $\log x + \log z = \log x\cdot z$.

Case II: Two Parallel Scales and an Intersecting Scale, All Straight Lines

Such a nomogram, the so-called Z-chart, is shown in Fig. 6. We have:

$$\frac{\alpha}{\gamma}=\frac{l-\beta}{\beta} \qquad (3)$$

which shows that this kind of nomogram is suited for equations of the following form:

$$\frac{f(x)}{h(z)}=g(y), \qquad \text{II}$$

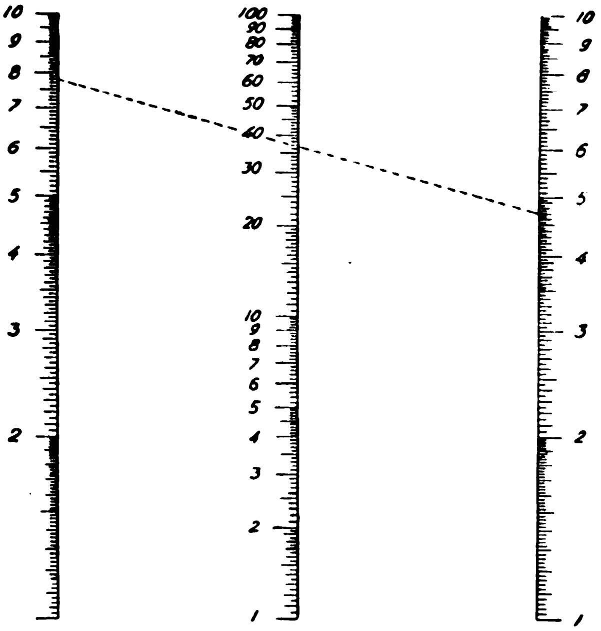


Fig. 5. A Multiplication Chart(1)

The scales should be so chosen that

$$\alpha=l_1\cdot f(x);\ \gamma=l_3\cdot h(z);\ \frac{l-\beta}{\beta}=\frac{l_1}{l_3}\cdot g(y),$$

$$i.e., \beta=\frac{l}{1+\frac{l_1}{l_3}\cdot g(y)}$$

It is sometimes an advantage that the y scale in the Z-charts contains the whole range from $g(y)=0$ to $g(y)=\infty$ between the points of intersection with the x and y scale.

Example 3: The Z-charts give a very simple representation of the calculations connected with Wheatstone's bridge. If the standard resistance is s, the reading on the slide wire a, the length of the wire 100, and the unknown quantity r, we have: $\frac{r}{s}=\frac{100-a}{a}$. Comparing this expression with Equation (3), we see that they are identical if we put: $\alpha=l_1\cdot r$; $\gamma=l_1\cdot s$; $\beta=a\cdot\frac{l}{100}$. This gives a chart like Fig. 7 with simple linear scales. The dotted line shows that the reading $a=56.0$ with a standard $s=6.00$ gives $r=4.71$.

If, however, the standard had been $s=1.20$, the chart would have given only very poor accuracy. In such a case it is better to use a value of s which is two or five times too large, and afterwards correct the result. If $u=1.2$ and $a=56$, we use the value $u=5\times1.2=6.0$ and $a=56$, which give $r=4.71$; the correct r is then $\frac{1}{5}\times4.71=0.942$.

This method is a little more laborious; it helps a little if there are provided several sets of figures along the scales, preferably in different colors so that figures of the same colors give corresponding readings (cf. Figs. 16 and 18). But in the case of Wheatstone's bridge it will be found much better to build the graph with three parallel scales, the type described in the previous section. The equation is easily transformed to the form I by writing:

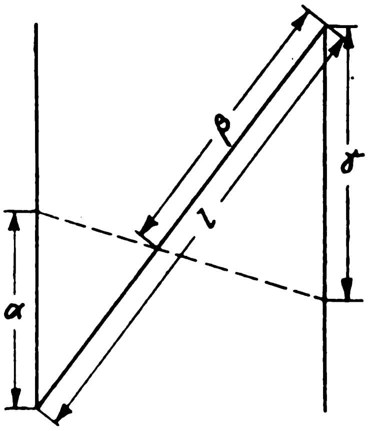


Fig. 6. Case *II:* A Z-chart. (Two Parallel Scales and an Intersecting Scale)

$$\log r=\log s+\log\frac{100-a}{a}.$$

The scales are now a little more difficult to make but the accuracy is the same for all values of r.

Case III: Two Parallel Straight Lines and a Curved Scale

The types I and II are both included in the third type, where the two scales are parallel straight lines and the third one any curve. This is a fairly general type of chart and permits a simple representation of a large number of equations.

In deriving the equations of this kind of nomogram we will introduce the "parallel coördinates" u and v, measured along two parallel coördinate axes U and V from the points of origin A and B (Fig. 8). We also use an ordinary Cartesian coördinate system with AB as Ξ-axis and a line, parallel to the U and V-axes and bisecting the distance between them, as H-axis. The equations of the U and V-axes in the Ξ, H system are $\xi+\delta=0$ and $\xi-\delta=0$.

In the parallel coördinate system a straight line MN is given by two coördinates (u, v), *i.e.*, by the same analytical expression as a point in Cartesian coördinates. Conversely, a point is expressed in parallel coördinates in the same manner as a straight line in Cartesian coördinates, *viz.*, by a linear equation $au+bv+c=0$. To prove this, we consider a point P and draw the lines AP: $(0, \beta)$ and BP: $(\alpha, 0)$ and furthermore any line MPN: (u, v). We now have from similar triangles

---

(1) The nomograms given in Figs. 5 to 14 are only illustrations of the theories and are not intended for practical purposes, as they should then be made much larger, such as Figs. 16 and 18 to 20.

$$\frac{\delta+\xi}{\delta-\xi}=\frac{\alpha-u}{v}=\frac{u}{\beta-v} \tag{4}$$

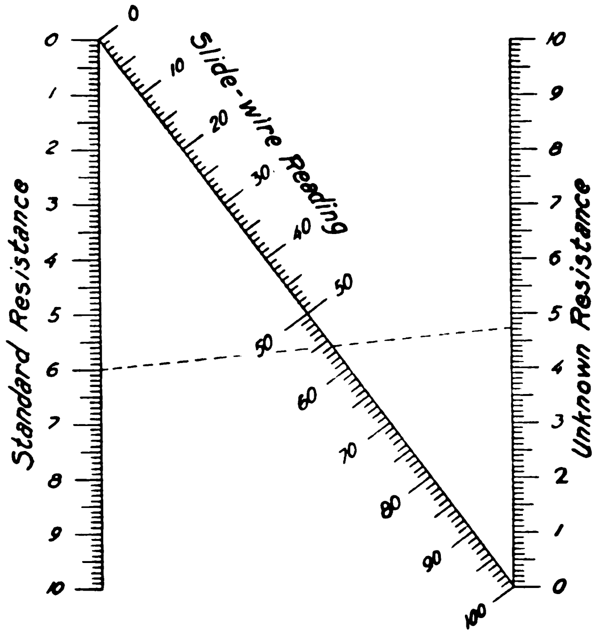


Fig. 7. A Z-chart Applied to Resistance Measurements by the Wheatstone Bridge

From this we get
$$\frac{u}{\alpha}+\frac{v}{\beta}=1 \tag{5}$$

or, letting $a=-\frac{c}{\alpha}$, $b=-\frac{c}{\beta}$, where c is an arbitrary constant,

$$au+bv+c=0. \tag{6}$$

This equation must be satisfied by the coördinates (u, v) of the line MN, if it shall pass through the point P; and conversely, all solutions (u, v) of Equation (6) represent straight lines through P; *i.e.*, Equation (6) represents the point P. Expressions for the Cartesian coördinates (ξ, η) of P in terms of the coefficients of Equations (5) or (6) can be derived from Fig. 8 in the following manner:

$$\eta=\beta\cdot\frac{\delta+\xi}{2\delta}=\alpha\cdot\frac{\delta-\xi}{2\delta} \tag{7}$$

$$\left.\begin{aligned}\therefore\ \xi&=\delta\cdot\frac{\alpha-\beta}{\alpha+\beta}=-\delta\cdot\frac{a-b}{a+b}\\ \eta&=\frac{\alpha\beta}{\alpha+\beta}=\frac{-c}{a+b}\end{aligned}\right| \tag{8}$$

We now graduate the U and V axes with the scales $u=l_1\cdot f(x)$, $v=l_2\cdot g(y)$; then any line through P will determine corresponding values of x and y which satisfy the equation $al_1 f(x)+bl_2\,g(y)+c=0$; and if we choose a number of points P such that

$$a=\frac{1}{l_1}\cdot h(z),\ b=\frac{1}{l_2}\cdot\varphi(z),\ c=\psi(z)$$

or

$$\alpha=-l_1\cdot\frac{\psi(z)}{h(z)},\ \beta=-l_2\cdot\frac{\psi(z)}{\varphi(z)}$$

and mark them with the corresponding values of z, then lines through any of these points will determine a set of values (x, y, z) which satisfies the equation

$$f(x)\cdot h(z)+g(y)\cdot\varphi(z)+\psi(z)=0 \qquad \text{III}$$

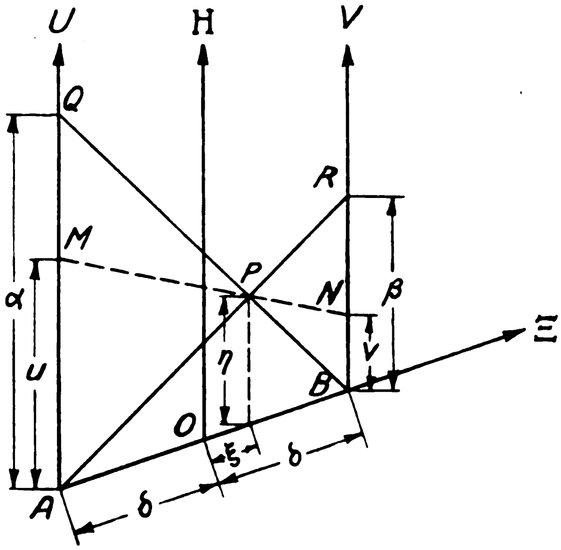


Fig. 8. Case *III*: Construction of a Nomogram Involving Two Parallel Straight Lines and a Curved Scale

The collection of points P is a curve, *viz.*, the scale for z. The equation of P is hence

$$\frac{1}{l_1}h(z)\cdot u+\frac{1}{l_2}\varphi(z)\cdot v+\psi(z)=0,$$

$$i.e.,\ a=\frac{1}{l_1}\cdot h(z),\ b=\frac{1}{l_2}\cdot\varphi(z),\ c=\psi(z),$$

and by means of the transformation given by Equations (8) we obtain the following Cartesian equation of the z scale:

$$\left.\begin{aligned}\xi&=-\delta\cdot\frac{l_2\cdot h(z)-l_1\cdot\varphi(z)}{l_2\cdot h(z)+l_1\cdot\varphi(z)}=-\delta\cdot\frac{h(z)-\frac{l_1}{l_2}\cdot\varphi(z)}{h(z)+\frac{l_1}{l_2}\cdot\varphi(z)}\\ \eta&=\frac{-l_1 l_2\cdot\psi(z)}{l_2\cdot h(z)+l_1\cdot\varphi(z)}=-l_1\cdot\frac{\psi(z)}{h(z)+\frac{l_1}{l_2}\cdot\varphi(z)}\end{aligned}\right| \tag{9}$$

The Equations (9) are very useful, permitting the direct construction of the curved z scale when an Equation **III** is given.

However, the constants l_1, l_2, etc., must be chosen first. Now it is seen from Fig. 8 that variations of the angle between the Ξ and H-axes, or of δ or l_1 $\left(\text{but with a constant ratio } \frac{l_1}{l_2}\right)$ only give simple homologous transformations of the whole graph; but a variation of the ratio $\frac{l_1}{l_2}$ gives more radical changes of the z curve; for instance, the z curve may change from a hyperbola to a parabola or an ellipse or a straight line. Therefore, in constructing a nomogram of this kind, the most suitable value, positive or negative, of $\frac{l_1}{l_2}$ should first be found (by making a few rough sketches), and then the values of the other constants can be adjusted according to the ranges of values of x, y, and z, which it is desired to represent.

Example 4: As an example we will consider nomograms which will give the solutions of equations of the form:

$$z^n+pz+q=0,$$

containing the three variables z, p, and q. If we write the equation

$$pz+q+z^n=0,$$

it is seen to correspond to Equation III when we put $h(z)=z$, $\varphi(z)=1$, $\psi(z)=z^n$, $f(x)=p$, $g(y)=q$. The scales for p and q are linear, $l_1\cdot p$ along the U-axis and $l_2\cdot q$ along the V-axis. The equations for the third scale are, according to Equations (9):

$$\xi=-\delta\cdot\frac{z-\frac{l_1}{l_2}}{z+\frac{l_1}{l_2}} \qquad \eta=-l_1\cdot\frac{z^n}{z+\frac{l_1}{l_2}}.$$

Choosing $l_1=l_2$, we get:

$$\xi=\delta\cdot\frac{1-z}{1+z} \qquad \eta=-l_1\cdot\frac{z^n}{1+z}.$$

The chart is shown in Fig. 9 where the scale A corresponds to $n=2$, B to $n=3$, a quadratic and a cubic equation respectively.

Only the part of the scale corresponding to positive z is drawn. The possible negative roots in the quadratic equation are found by using $-p$ and $+q$ in the chart; and the possible negative roots in the cubic equation are found by using $+p$ and $-q$. This is because, if $-\gamma$ is a root of $z^2+pz+q=0$, then $+\gamma$ must be a root of $z^2-pz+q=0$; and if $-\gamma$ is a root of $z^3+pz+q=0$, $+\gamma$ must be a root of $-z^3-pz+q=0$, or of $z^3+pz-q=0$.

The dotted lines in Fig. 9 show that the positive roots of $z^3-7z+6=0$ are $+1$ and $+2$ while the numerical value 3 of the negative root is found by using p and $-q$, *i.e.*, $p=-7$ and $q=-6$. Besides, one of the lines shows that the roots of the quadratic $z^2-7z+6=0$ are $+1$ and $+6$.

The curve B allows us to solve any cubic

$$x^3+ax^2+bx+c=0$$

because Cardan's transformation, $z=x+\frac{a}{3}$, reduces it to

$$z^3+\left(b-\frac{a^2}{3}\right)z+\frac{2}{2z}a^3-\frac{ab}{3}+c=0.$$

Case IV: Three Curved Scales

The most general case is obtained if all three scales are arbitrary curves. As before, we must be able to write the equations of these curves in parallel coördinates in the following manner:

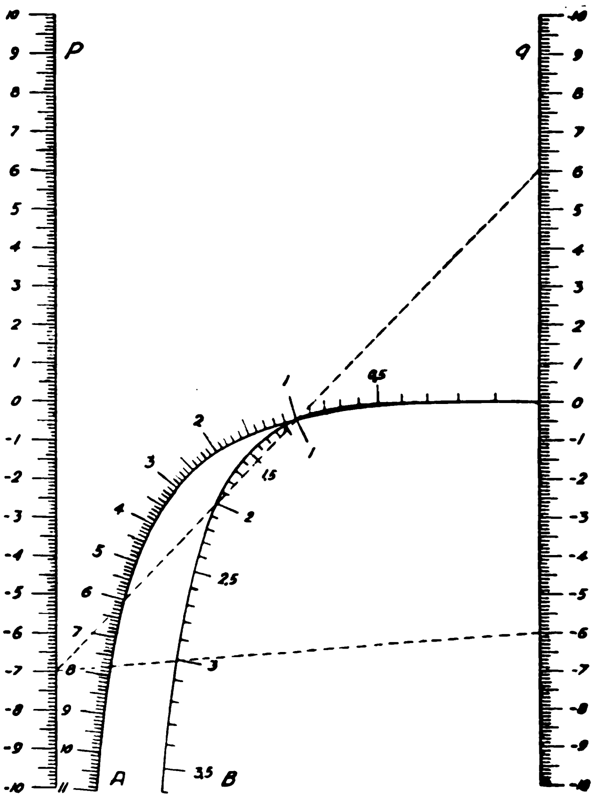


Fig. 9. Nomograms Applied to Algebraic Equations

$$\left.\begin{aligned} u\cdot h_1(x)+v\cdot\varphi_1(x)+\psi_1(x)&=0,\\ u\cdot h_2(y)+v\cdot\varphi_2(y)+\psi_2(y)&=0,\\ u\cdot h_3(z)+v\cdot\varphi_3(z)+\psi_3(z)&=0,\end{aligned}\right\}\quad(10)$$

letting $l_1=l_2=1$ for simplicity.

If now three points x, y, and z shall lie in a straight line $(u\,v)$, its coördinates (u, v) must satisfy the three Equations (10). The condition that this should be possible is expressed by eliminating u and v between the three equations, and is in determinant form:

$$\begin{vmatrix} h_1(x) & \varphi_1(x) & \psi_1(x)\\ h_2(y) & \varphi_2(y) & \psi_2(y)\\ h_3(z) & \varphi_3(z) & \psi_3(z)\end{vmatrix}=0 \qquad \text{IV}$$

or, if the determinant is multiplied out:

$$\left.\begin{aligned} &h_1(x)\cdot\{\varphi_2(y)\cdot\psi_3(z)-\psi_2(y)\cdot\varphi_3(z)\}\\ &+\varphi_1(x)\{\psi_2(y)\cdot h_3(z)-h_2(y)\cdot\psi_2(z)\}\\ &+\psi_1(x)\{h_2(y)\cdot\varphi_3(z)-\varphi_2(y)\cdot h_3(z)\}=0\end{aligned}\right\}\quad \textbf{IVa}$$

If there is given an equation of the form **IV**, and the three scales (Fig. 10) for x, y, and z are drawn, any straight line $(u\,v)$ will determine a set of values of x, y, and z, which satisfies Equation **IV**. The form **IV** is the most general type of equation of three variables which can be represented in alignment charts. If an equation can not be written in this form, it is not possible to represent it in alignment charts.

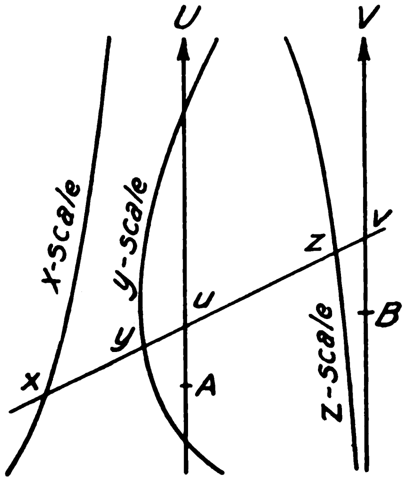


Fig. 10. **Case *IV*: Three Curved Scales**

As in the previous case, different constants have to be chosen to determine the best form of the nomogram. All possible forms of the nomogram are obtained by multiplying **IV** by an arbitrary determinant

$$D=\begin{vmatrix}\lambda_1 & \mu_1 & \nu_1\\ \lambda_2 & \mu_2 & \nu_2\\ \lambda_3 & \mu_3 & \nu_3\end{vmatrix}$$

where $D\neq 0$. This changes all the scales (Fig. 10) and is called a homographic transformation. The new scales are given by the following expressions:

$$\left.\begin{aligned} &u\cdot\{\lambda_1h_1+\mu_1\varphi_1+\nu_1\psi_1\}+v\cdot\{\lambda_2h_1+\mu_2\varphi_1+\nu_2\psi_1\}\\ &\qquad+\lambda_3h_1+\mu_3\varphi_1+\nu_3\psi_1=0,\\ &u\cdot\{\lambda_1h_2+\mu_1\varphi_2+\nu_1\psi_2\}+v\cdot\{\lambda_2h_2+\mu_2\varphi_2+\nu_2\psi_2\}\\ &\qquad+\lambda_3h_2+\mu_3\varphi_2+\gamma_3\psi_2=0,\\ &u\cdot\{\lambda_1h_3+\mu_1\varphi_3+\nu_1\psi_3\}+v\cdot\{\psi_2h_3+\mu_2\varphi_3+\nu_2\psi_3\}\\ &\qquad+\lambda_3h_3+\mu_3\varphi_3+\nu_3\psi_3=0.\end{aligned}\right\}(10a)$$

If it is desired to represent the following ranges of the three variables:

$$a_1\leq x\leq a_2,\ b_1\leq y<b_2,\ c_1\leq z\leq c_2,$$

we can, for instance, determine D so that the x scale passes through $u=0$ for $x=a_1$ and through $u=1$ for $x=a_2$, and the z scale passes through $v=0$ for $z=c_1$ and $v=1$ for $z=c_2$. These conditions give eight equations between the nine elements of D, as, for instance, $u=1$ for $x=a_2$ (and for all values of v) demands that:

$$1\cdot h'_1(a_2)+\psi'_1(a_2)=0,\ \varphi'_1(a_2)=0 \qquad (11)$$

where we have put:

$$h'_1=\lambda_1h_1+\mu_1\varphi_1+\gamma_1\psi_1;\quad \varphi'_1=\lambda_2h_1+\mu_2\varphi_1+\gamma_2\psi_1;$$
$$\psi'_1=\lambda_3h_1+\mu_3\varphi_1+\gamma_3\psi_1.$$

Then there is only one element left to be chosen arbitrarily (but such that the determinant D is different from zero). An example of such calculations is given in Example 7.

Equation **IV** is the most general type of equation which can be represented in alignment charts. It would therefore be of interest to find a test which could show definitely if it is possible to reduce a given equation $F(x, y, z)=0$ to the form **IV**. This problem is not yet solved. But it is practical to use the following scheme:

Let (a_1, b_1, c_1), (a_2, b_2, c_2), (a_3, b_3, c_3) be three sets of roots of the equation $F(x, y, z)=0$. Then try to determine such coefficients λ_1, $\mu_1\cdots$, that the following equation is identically satisfied:

$$F(x,y,z)=\begin{vmatrix}\lambda_1F(x,b_1,c_1) & \mu_1F(a_1,y,c_1) & \nu_1F(a_1,b_1,z)\\ \lambda_2F(x,b_2,c_2) & \mu_2F(a_2,y,c_2) & \nu_2F(a_2,b_2,z)\\ \lambda_3F(x,b_3,c_3) & \mu_3F(a_3,y,c_3) & \nu_2F(a_3,b_3,z)\end{vmatrix}\qquad (12)$$

This method often leads to the solution, if there is any.

However, it is possible to express the necessary and sufficient conditions under which an equation $F(x, y, z)=0$ can be reduced to the form of either **I** or **III**. Letting

$$\frac{\partial F}{\partial x}:\frac{\partial F}{\partial z}=\frac{\partial z}{\partial x}=p_1,\qquad \frac{\partial F}{\partial y}:\frac{\partial F}{\partial z}=\frac{\partial z}{\partial y}=p_2,$$
$$\frac{\partial p_1}{\partial y}=\frac{\partial p_2}{\partial x}=\frac{\partial^2 z}{\partial x\partial y}=s,\quad \frac{p_1}{p_2}=q,$$

then the equation can be reduced to the form **I**, if

$$\frac{\partial^2\log q}{\partial x\partial y}=0 \qquad (13)$$

Writing furthermore:

$$\frac{s}{p_1p_2}=u,\ \frac{1}{p_1p_2}\cdot\frac{\partial^2\log q}{\partial x\partial y}=v,\ \frac{p_2\dfrac{\partial v}{\partial x}-p_1\dfrac{\partial v}{\partial y}}{p_2\dfrac{\partial u}{\partial x}-p_1\dfrac{\partial u}{\partial y}}=w,$$

then the equation can be reduced to the form **III**, if

$$\frac{\dfrac{\delta w}{\delta x}}{p_1}=\frac{\dfrac{\delta w}{\delta y}}{p_2}=v-uw \qquad (14)$$

If the Equation (13) or (14) is satisfied, the expression **I** or **III** can be determined by successive integrations and transformations.⁽²⁾

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(2) d'Ocagne: *Traité de nomographie*, p. 418 and ff.

Case V: Four or More Variables

In the case of four or more variables, several charts may be introduced, which can be moved with respect to each other, etc., or the principles of tables with three variables can be expanded after one of the following two methods.

The first method is to change $F\ (x, y, z, u) = 0$ to two equations

$$F_1\ (x, y, r) = 0; \quad F_2\ (z, u, r) = 0 \qquad (15)$$

for instance: $r = f_1\ (x, y) = f_2\ (z, u)$, and to give these such a form that it is possible to give them a common r scale; *i.e.*, to bring them to the form

$$\begin{vmatrix} h\ (r) & \varphi\ (r) & \psi\ (r) \\ h_1(x) & \varphi_1(x) & \psi_1(x) \\ h_2(y) & \varphi_2(y) & \psi_2(y) \end{vmatrix} = 0, \quad \begin{vmatrix} h\ (r) & \varphi\ (r) & \psi\ (r) \\ H_1(z) & \Phi_1(z) & \Psi_1(z) \\ H_2(u) & \Phi_2(u) & \Psi_2(u) \end{vmatrix} = 0 \qquad (15a)$$

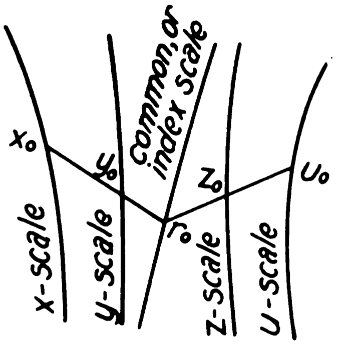


Fig. 11. Nomogram for Four Variables Using a Common, or Index, Scale

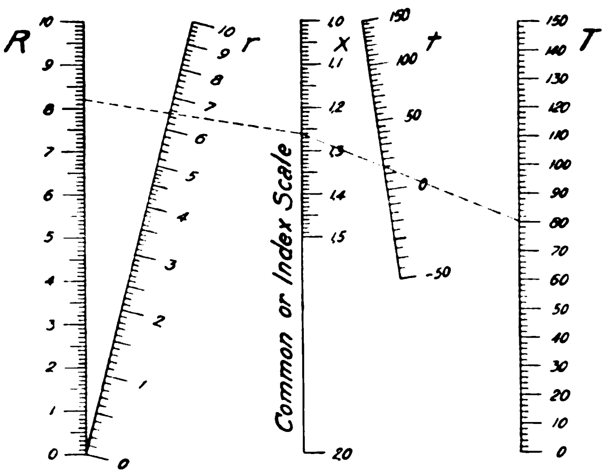


Fig. 12. A Nomogram for Determining Temperature from Measurements of Resistance

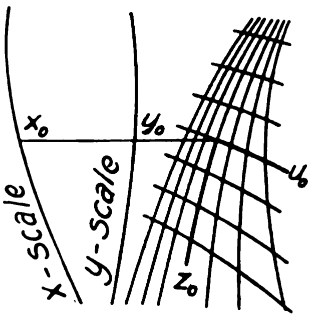


Fig. 13. Nomogram for Four Variables Using a Family of Curves

All five scales are drawn in the same graph (Fig. 11), and if now the values (x_0, z_0, u_0) of x, z, and u are given, we first determine the r_0 which corresponds to z_0 and u_0, and then use this r_0 together with x_0 to give us y_0. This demands two adjustments of the variable straight line.

Example 5: The average temperature rise of a copper winding in an electric machine is determined by measuring the electric resistance of it cold and warm, r and R. If the corresponding temperatures are t and T degrees centigrade, we have:

$$T - t = \frac{R - r}{r}\ (234.5 + t).$$

This expression can be rewritten in the form

$$\frac{R}{r} = \frac{234.5 + T}{234.5 + t} = x,$$

from which it appears that we can divide the problem up in two, *viz.*, first the determination of x from R and r, and next the determination of T from t and x:

$$\frac{R}{x} = r; \qquad \frac{234.5 + T}{x} = 234.5 + t$$

These equations are both of the form II and can be represented in Z-charts, using in the first chart:

$$\alpha = l_1 \cdot R; \ \gamma = l_3 \cdot x; \ \beta = \frac{l}{1 + \frac{l_1}{l_3} \cdot r}$$

and in the other:

$$\alpha' = l'_1 \cdot (234.5 + T); \ \gamma' = \gamma = l_3 \cdot x; \ \beta' = \frac{1}{1 + \frac{l'_1}{l_3} \cdot (234.5 + t)}$$

With $\frac{l_1}{l_3} = \frac{1}{10}$ and $\frac{l'_1}{l_3} = \frac{1}{150}$ this gives the nomogram Fig. 12. It is shown in dotted lines that $R = 0.82$ ohms, $r = 0.65$ ohms, and $t = 15$ degrees give $T = 80.2$ degrees with $x = 1.261$ as intermediate value.

The graduation of the x scale has no influence on the results; any graduation, or none at all, would do. But it is practical to have some kind of graduation, as it helps to fix the point which must be used again.

The second principle is to write the equation $F\ (x, y, z) = 0$ in the following form:

$$\begin{vmatrix} h_1(x) & \varphi_1(x) & \psi_1(x) \\ h_2(y) & \varphi_2(y) & \psi_2(y) \\ H_3(z, u) & \Phi_3(z, u) & \Psi_3(z, u) \end{vmatrix} = 0 \qquad (16)$$

Here, the x and y scale can be drawn just as for equations in three variables, and besides, a z scale can be drawn for every fixed value of u or a u scale for every fixed value of z (Fig. 13). In this way we get a $z - u$ coördinate system and have to connect, say, the x_0 point with the point of intersection between the proper z_0 and u_0 curves to obtain y_0. We have here only one adjustment of the variable straight line but we must use a family of z and u scales. This is practical if either the influence of u on the position of the z scales is not very great, or if ordinarily only a certain number of fixed values of u are used, so that we have to draw only a small number of z scales, one for every value of u.

Example 6: The efficiency (η) of electric transformers which have partly constant losses (iron losses) W_0, partly losses which are proportional to the current squared, $W_K \cdot \left(\frac{I}{I_{1/1}}\right)^2$ (copper losses), is determined by

$$100-\eta=\frac{W_0+W_K\cdot\left(\frac{I_0}{I_{1/1}}\right)^2}{\left(\frac{I}{I_{1/1}}\right)\cdot\cos\varphi\cdot KVA\cdot 1000+W_0+W_K\cdot\left(\frac{I}{I_{1/1}}\right)^2}\cdot 100$$

if η is expressed in per cent. We define the load-factor $\alpha=\frac{I}{I_{1/1}}$, and the percentage losses at full load:

$$w_0=\frac{W_0}{\cos\varphi\cdot KVA\cdot 1000}\cdot 100 \text{ and } w_k=\frac{W_k}{\cos\varphi\cdot KVA\cdot 1000}\cdot 100$$

(*i.e.*, the losses in per cent of full-load killowatts at the given cos φ) and insert these values in the equation:

$$100-\eta=\frac{w_0+\alpha^2 w_k}{100\,\alpha+w_0+\alpha^2 w_k}\cdot 100$$

Now we can rewrite this in the following form:

$$w_0+\alpha^2 w_k+100\,\alpha\cdot\left(1-\frac{100}{\eta}\right)=0.$$

This equation corresponds to **III** when we put: $f(x)=w_0$; $g(y)=w_k$; $h(z)=1$; $\varphi(z)=\alpha^2$; $\psi(z)=100\,\alpha\cdot\left(1-\frac{100}{\eta}\right)$, and Equations (9) now determine for every given value of α a scale for η, while the w_0 and w_k scales are fixed:

$$u=l_1\cdot w_0 \qquad v=l_2\cdot w_k$$

$$\xi=-\delta\cdot\frac{1-\frac{l_1}{l_2}\alpha^2}{1+\frac{l_1}{l_2}\alpha^2} \qquad \eta=-l_1\cdot\frac{100\,\alpha\cdot\left(1-\frac{100}{\eta}\right)}{1+\frac{l_1}{l_2}\alpha^2}$$

If we let $\frac{l_1}{l_2}=1$ and draw the η scales for $\alpha=\frac{1}{4},\frac{1}{2},\frac{3}{4},\frac{1}{1},\frac{5}{4}$, and $\frac{3}{2}$, we get a nomogram like Fig. 14. This chart is very much used in practice.

We had another example of this type of tables in Ex. 4 and the corresponding Fig. 9, where there really are four variables z, p, q, and n, and where we have drawn different z scales for different fixed values of n.

Resumé

From the foregoing summary of the most important types of alignment charts it will be seen that these are well suited for numerical computation. The accuracy generally exceeds that of a slide-rule; the interpolations are unidimensional and can be facilitated by fine graduations; and the nomograms are reciprocal so that any of the variables can be determined from the others though it may not be possible to express it explicitly in mathematical formulas. Only the number of variables must not be too large (three or four), and it must be possible to reduce the equations in some way or other to the form **IV**.

In this way, nomograms have their field in computation just as well as the slide rule, the adding machine, and numerical tables. Especially, they apply to problems in three or four variables, which are repeated so often that it is worth while to draw a chart.

NOMOGRAMS WITH TWO DEPENDENT VARIABLES

We shall now consider the problem of nomograms for four variables, two of which are independent. This problem is often met with in calculations with vectors. An equation between two vectors:

$$F(\overline{A})=G(\overline{B}) \tag{17}$$

really means two equations between four variables, since each vector consists of two elements, for instance, $\overline{A}=p+jq$ or $\overline{A}=r\cdot e^{j\theta}$, and the sign of equality applies to both the real and the complex components. If now two of these four elements are given, they determine the other two; consequently it must be possible to solve the problem by adjusting one position of the variable straight line in a nomogram.

Let the components of A in Equation (17) be x and y, and the components of $\overline{B}$: u and v. Now suppose that we can eliminate v and u respectively between the two equations which result from Equation (17), then we arrive at two new equations:

$$f(x,y,u)=0;\quad g(x,y,v)=0 \tag{18}$$

If these two equations can be reduced to the form **IV**, we can make a nomogram for each of them. Then the problem is to make the x and y scales of the two nomograms equal so that we can superimpose them and obtain one nomogram with only four scales, *viz.*, the common x and y scales, a corresponding u scale, and also a corresponding v scale (Fig. 15). A straight line through given points x_0, y_0 on the x and y scales now determines the corresponding u and v simultaneously; but the same line gives us x and y, if u and v are given, so that the chart is entirely reciprocal. This reciprocity is of importance both for the utility of the nomogram and also for its construction, since often much simpler equations are obtained by the elimination of one pair of the variables (x, y) and (u, v) than by the elimination of the other.

The process of making the two sets of x and y scales equal is expressed analytically by writing Equations (18) in the form:

$$\begin{vmatrix} h_1(x) & \varphi_1(x) & \psi_1(x) \\ h_2(y) & \varphi_2(y) & \psi_2(y) \\ h_3(u) & \varphi_3(u) & \psi_3(u) \end{vmatrix}=0,\ \begin{vmatrix} H_1(x) & \Phi_1(x) & \Psi_1(x) \\ H_2(y) & \Phi_2(y) & \Psi_2(y) \\ H_3(v) & \Phi_3(v) & \Psi_3(v) \end{vmatrix}=0 \tag{18a}$$

where:

$$\frac{h_1(x)}{H_1(x)}=\frac{\varphi_1(x)}{\Phi_1(x)}=\frac{\psi_1(x)}{\Psi_1(x)};\ \frac{h_2(y)}{H_2(y)}=\frac{\varphi_2(y)}{\Phi_2(y)}=\frac{\psi_2(y)}{\Psi_2(y)} \tag{19}$$

since the corresponding Equations (10) will then represent the same scales.

The values of the fractions in Equation (19) can always be made equal to unity by multiplying the first and second row of the determinant (18a) by suitable functions. The procedure of reducing Equations (18) to the form (18a) is therefore this:

Write (18) in determinant form; then multiply the first and second row by such functions of x and y respectively that as far as possible the same types of functions appear in the first and second determinant. Finally try to submit each of the determinants to such a homographic transformation that the following equations are identically satisfied:

$$\left.\begin{aligned} h_1(x)=H_1(x);\ \varphi_1(x)=\Phi_1(x);\ \psi_1(x)=\Psi_1(x) \\ h_2(y)=H_2(y);\ \varphi_2(y)=\Phi_2(y);\ \psi_2(y)=\Psi_2(y) \end{aligned}\right\} \quad (19a)$$

As mentioned previously, these transformations are carried out by multiplying each of the two equations (in determinant form) by a determinant:

$$D=\begin{vmatrix} \lambda_1 & \mu_1 & \nu_1 \\ \lambda_2 & \mu_2 & \nu_2 \\ \lambda_3 & \mu_3 & \nu_3 \end{vmatrix} \neq 0.$$

Equations (19a) give at least six relations between the 18 elements $\lambda_1, \lambda_2 \cdots \nu_2, \nu_3$, and the rest of them can be chosen such as to give the chart a suitable form—if it is possible at all to solve the problem.

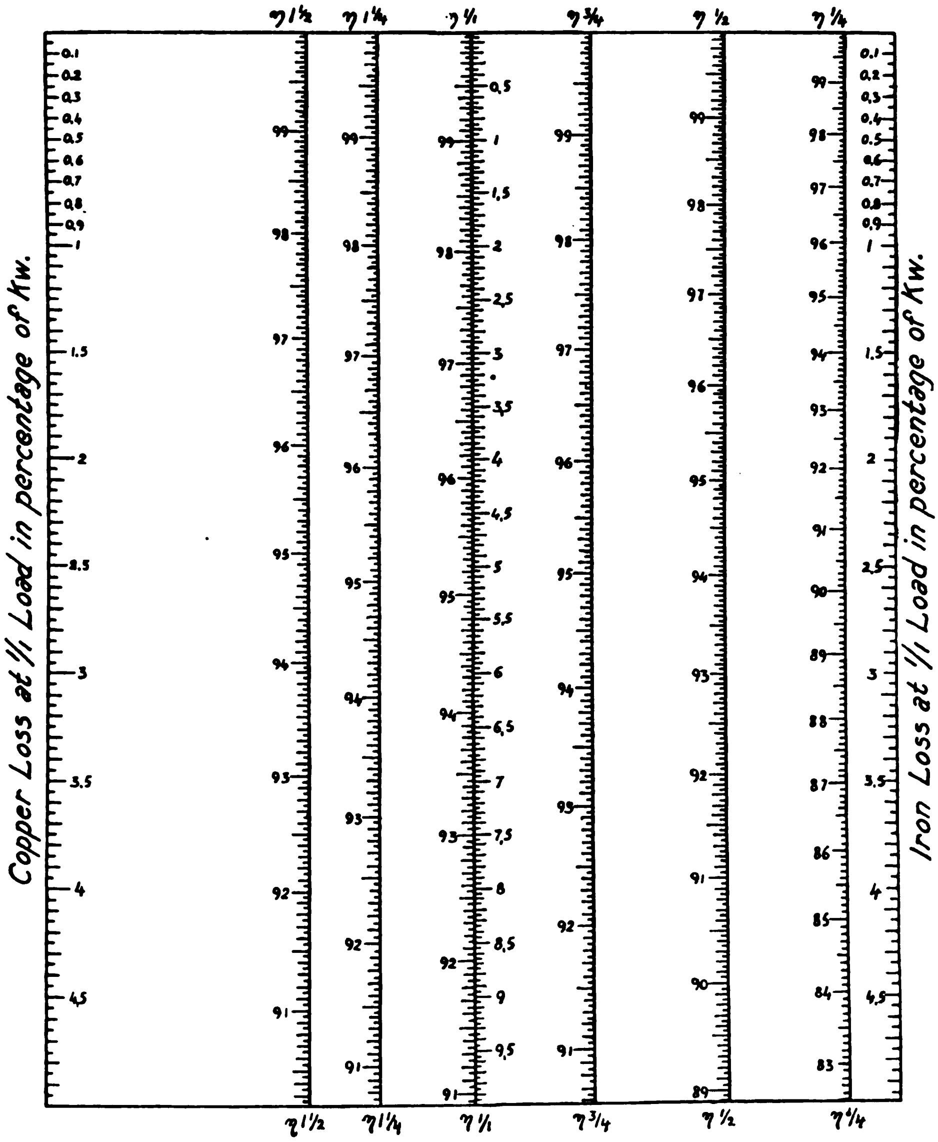


Fig. 14. Nomogram Applied to Determination of Efficiency of Transformer at Different Loads

Example 7: We will illustrate the calculations in the case of a chart for conversion between polar and rectangular coördinates. This case will, however, also be treated later in a simpler manner.

The equations of conversion are:

$$x^2+y^2=r^2;\quad y=x\tan\theta \qquad \text{(a)}$$

To obtain similar functions of x and y, we square the second equation and then rewrite both equations in determinant form:

$$\begin{vmatrix} x^2 & -1 & 1 \\ y^2 & 1 & 0 \\ r^2 & 0 & 1 \end{vmatrix} = 0 \qquad \begin{vmatrix} x^2 & 1 & 0 \\ y^2 & 0 & -1 \\ 0 & \tan^2\theta & 1 \end{vmatrix} = 0 \qquad \text{(b)}$$

Now we multiply these equations by the following determinants:

$$D = \begin{vmatrix} \lambda_1 & \mu_1 & \nu_1 \\ \lambda_2 & \mu_2 & \nu_2 \\ \lambda_3 & \mu_3 & \nu_3 \end{vmatrix} \qquad D' = \begin{vmatrix} \lambda'_1 & \mu'_1 & \nu'_1 \\ \lambda'_2 & \mu'_2 & \nu'_2 \\ \lambda'_3 & \mu'_3 & \nu'_3 \end{vmatrix} \qquad \text{(c)}$$

This gives two new determinant equations, which correspond to the following equations (in parallel coördinates) for the scales, in the same manner as Equations (10) correspond to the determinant IV:

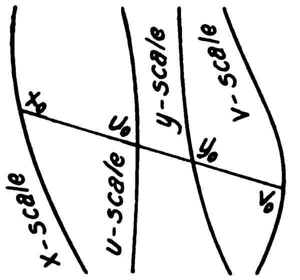


Fig. 15. Nomogram for Four Variables, Only Two of which Are Independent

$$\left.\begin{aligned} &u\cdot(\lambda_1x^2-\mu_1+\nu_1) +v\cdot(\lambda_2x^2-\mu_2+\nu_2) +(\lambda_3x^2-\mu_3+\nu_3) =0 \\ &u\cdot(\lambda_1y^2+\mu_1) +v\cdot(\lambda_2y^2+\mu_2) +(\lambda_3y^2+\mu_3) =0 \\ &u\cdot(\lambda_1r^2+\nu_1) +v\cdot(\lambda_2r^2+\nu_2) +(\lambda_3r^2+\nu_3) =0 \end{aligned}\right\} \text{(d)}$$

$$\left.\begin{aligned} &u\cdot(\lambda'_1x^2+\mu'_1) +v\cdot(\lambda'_2x^2+\mu'_2) +(\lambda'_3x^2+\mu'_3) =0 \\ &u\cdot(\lambda'_1y^2-\nu'_1) +v\cdot(\lambda'_2y^2-\nu'_2) +(\lambda'_3y^2-\nu'_3) =0 \\ &u\cdot(\mu'_1\tan^2\theta+\nu'_1)+v\cdot(\mu'_2\tan^2\theta+\nu'_2)+(\mu'_3\tan^2\theta+\nu'_3)=0 \end{aligned}\right\} \text{(d}'\text{)}$$

If the two x scales and also the two y scales shall coincide, their equations must be identical, *i.e.*, $\lambda_1x^2-\mu_1+\nu_1=\lambda'_1x^2+\mu'_1$, etc., which results in the following relations between the elements of D and D':

$$\lambda_1=\lambda'_1 \qquad \lambda_2=\lambda'_2 \qquad \lambda_3=\lambda'_3 \qquad \text{(e)}$$

$$-\mu_1+\nu_1=\mu'_1 \qquad -\mu_2+\nu_2=\mu'_2 \qquad -\mu_3+\nu_3=\mu'_3 \qquad \text{(f)}$$

$$\mu_1=-\nu'_1 \qquad \mu_2=-\nu'_2 \qquad \mu_3=-\nu'_3 \qquad \text{(g)}$$

Each set of values of $\lambda_1\lambda_2 \cdots \nu'_2\nu'_3$, which satisfies Equations (e), (f), and (g) and the conditions $D\neq 0$ and $D'\neq 0$, will give a chart with common x and y scales.

To obtain convenient scales we will furthermore demand that:

$$u=0 \text{ for } x=0$$
$$u=1 \text{ for } x=1$$
$$v=0 \text{ for } y=0$$

so that the points $x=0$ and $y=0$ fall in A and B (Fig. 8) and that the point $x=1$ falls in the point $u=1$ of the U axis. This gives the following conditions (cf. Equations (11)):

$$\mu_2=\nu_2 \qquad \mu'_2=0 \qquad \text{(h)}$$

$$\mu_3=\nu_3 \qquad \mu'_3=0 \qquad \text{(i)}$$

$$\lambda_2-\mu_2+\nu_2=0 \qquad \lambda'_2+\mu'_2=0 \qquad \text{(j)}$$

$$\left.\begin{aligned} &(\lambda_1-\mu_1+\nu_1)+(\lambda_3-\mu_3+\nu_3)=0 \\ &(\lambda'_1+\mu'_1)+(\lambda'_3+\mu'_3) \qquad =0 \end{aligned}\right\} \text{(k)}$$

$$\mu_1=0 \qquad \nu'_1=0 \qquad \text{(l)}$$

$$\mu_3=0 \qquad \nu'_3=0 \qquad \text{(m)}$$

Here, Equations (h) and (i) correspond to the condition $u=0$ for $x=0$, (j) and (k) to $u=1$ for $x=1$, and (l) and (m) to $v=0$ for $y=0$. The equations are written down corresponding both to Equations (d) and (d′); this is, however, superfluous, as Equations (e), (f), and (g) make the x and x' scales and the y and y' scales coincide. Thus Equations (e), (f) and (g) give nine, and (h) to (m) six independent relations between the eighteen elements λ_1, $\lambda_2 \cdots\cdots \nu'_2\,\nu'_3$. Therefore, they can all be expressed by $18-9-6=3$ of them, for instance, by λ_1, μ_2, and ν_1. If this is done, and the values inserted in the determinants D and D', they become:

$$D=\begin{vmatrix} \lambda_1 & 0 & \nu_1 \\ 0 & \mu_2 & \mu_2 \\ \lambda_1-\nu_1 & 0 & 0 \end{vmatrix} \qquad D'=\begin{vmatrix} \lambda_1 & \nu_1 & 0 \\ 0 & 0 & -\mu_2 \\ \lambda_1-\nu_1 & 0 & 0 \end{vmatrix} \qquad \text{(n)}$$

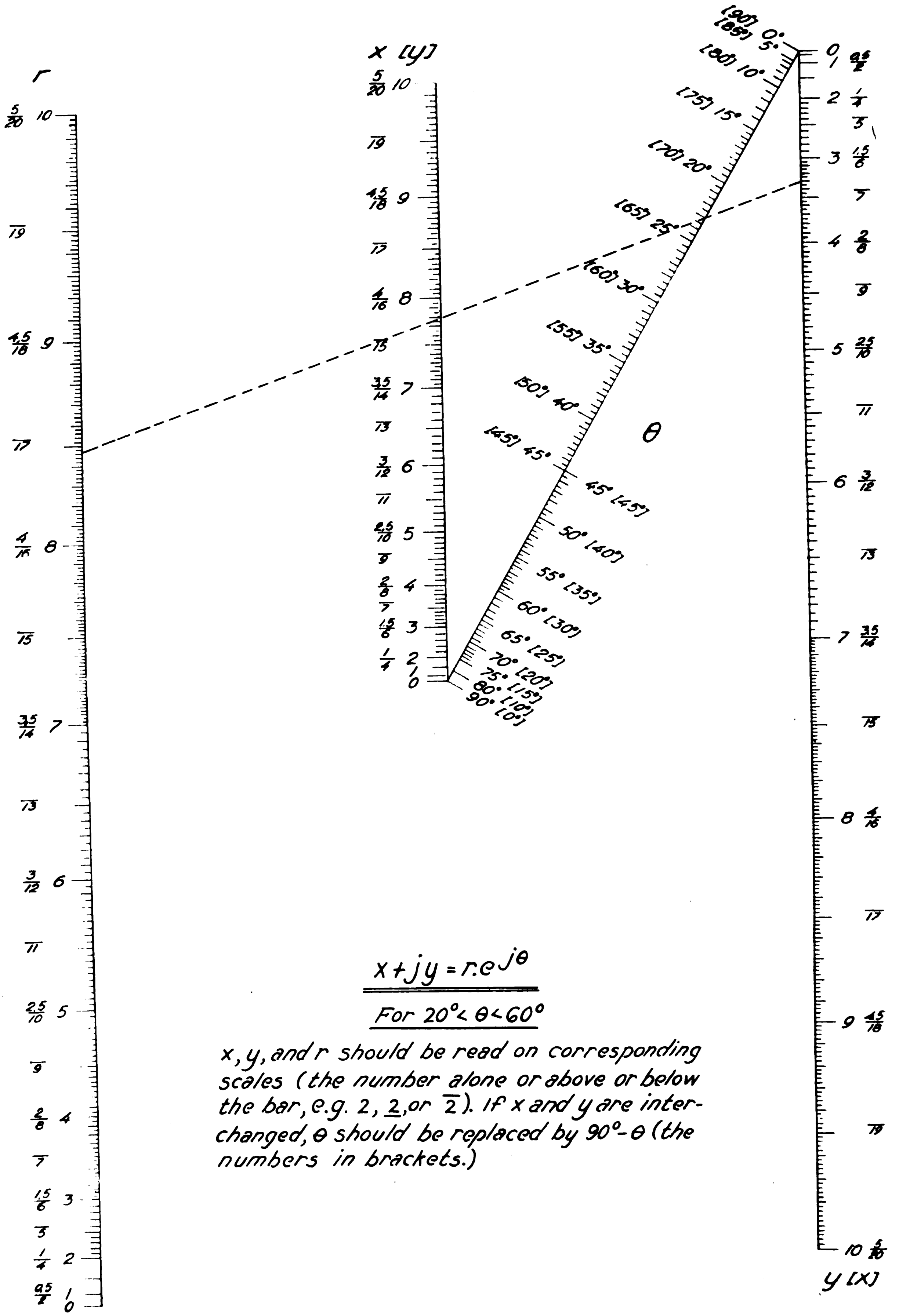
and inserting in Equations (d) and (d′), we get:

$$\left.\begin{aligned} &u\cdot(\lambda_1x^2+\nu_1)+v\cdot 0+(\lambda_1-\nu_1)\,x^2=0 \\ &u\cdot\lambda_1y^2+v\cdot\mu_2+(\lambda_1-\nu_1)y^2=0 \\ &u\cdot(\lambda_1r^2+\nu_1)+v\cdot\mu_2+(\lambda_1-\nu_1)\,r^2=0 \\ &u\cdot\nu_1\tan^2\theta+v\cdot(-\mu_2)=0 \end{aligned}\right\} \text{(o)}$$

Finally, we apply Equations (8) to obtain the parametric equations for the scales in Cartesian coördinates:

$$\left.\begin{aligned} &\text{The } x \text{ scale: } \xi=-\delta && \eta=-\frac{(\lambda_1-\nu_1)\,x^2}{\lambda_1x^2+\nu_1} \\ &\text{The } y \text{ scale: } \xi=-\delta\cdot\frac{\lambda_1y^2-\mu_2}{\lambda_1y^2+\mu_2} && \eta=-\frac{(\lambda_1-\nu_1)\,y^2}{\lambda_1y^2+\mu_2} \\ &\text{The } r \text{ scale: } \xi=-\delta\cdot\frac{\lambda_1r^2+\nu_1-\mu_2}{\lambda_1r^2+\nu_1+\mu_2} && \eta=-\frac{(\lambda_1-\nu_1)\,r^2}{\lambda_1r^2+\nu_1+\mu_2} \\ &\text{The } \theta \text{ scale: } \xi=-\delta\cdot\frac{\nu_1\tan^2\theta+\mu_2}{\nu_1\tan^2\theta-\mu_2} && \eta=0. \end{aligned}\right\} \text{(p)}$$

It is easily seen that all the preceding fractions can be expressed in terms of the ratios $\frac{\lambda_1}{\nu_1}$ and $\frac{\mu_2}{\nu_1}$. Therefore we must now choose these two quantities such that we obtain suitable scales for the ranges of x, y, r, and θ, which it is desired to represent. For instance, $\frac{\lambda_1}{\nu_1}=0$, and $\frac{\mu_2}{\nu_1}=-0.5$ give the nomogram shown in Fig. 16.


r
x [y]
θ
y [x]
[90] 0°
[85] 5°
[80] 10°
[75] 15°
[70] 20°
[65] 25°
[60] 30°
[55] 35°
[50] 40°
[45] 45°
45° [45]
50° [40]
55° [35]
60° [30]
65° [25]
70° [20]
75° [15]
80° [10]
90° [0]

$x + jy = r.e^{j\theta}$

For $20° < \theta < 60°$

x, y, and r should be read on corresponding scales (the number alone or above or below the bar, e.g. 2, $\underline{2}$, or $\overline{2}$). If x and y are interchanged, θ should be replaced by 90° − θ (the numbers in brackets.)

Fig. 16. A Typical Nomogram for Determining Vector Relationships

This method sometimes leads to rather complicated calculations. But it is often possible to treat the problem in the form III, *i.e.*, to reduce the Equations (18) to the form

$$\left.\begin{aligned} f(x)\cdot h(u)+g(y)\cdot\varphi(u)+\psi(u)&=0\\ f(x)\cdot H(v)+g(y)\cdot\Phi(v)+\Psi(v)&=0\end{aligned}\right\}\qquad(18b)$$

such that the same functions $f(x)$ and $g(y)$ appear in both equations, which gives identical x and y scales. In this case, the x and y scales are both straight lines. In this form we will treat some special nomograms of this type.

Nomogram for Conversion Between Polar and Rectangular Coördinates

The equations of conversion are the following:

$$r^2=x^2+y^2 \qquad \tan\theta=\frac{y}{x} \qquad (20)$$

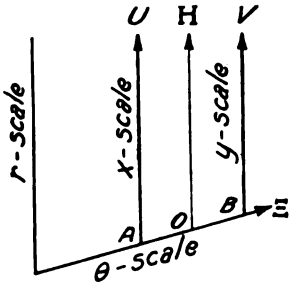


Fig. 17. Elementary Sketch Showing Principles of Nomograms for Conversion Between Polar and Rectangular Coördinates

We will rewrite them:

$$x^2+y^2-r^2=0 \qquad x^2\cdot\tan^2\theta-y^2=0 \qquad (20b)$$

Then they correspond to Equation (18b), and we have:

$$\begin{aligned} &f(x)=x^2 && g(y)=y^2 \\ h(r)=1 \qquad &\varphi(r)=1 && \psi(r)=-r^2 \\ H(\theta)=\tan^2\theta \qquad &\Phi(\theta)=-1 && \Psi(\theta)=0\end{aligned}$$

The x and y scales are quadratic and fall along the U and V-axes, $u=l_1x^2$, and $v=l_2y^2$ (Fig. 17); and from Equations (9) we obtain the equations for the r and θ scales as follows:

$$\text{For } r,\ \xi=-\delta\cdot\frac{1-\dfrac{l_1}{l_2}}{1+\dfrac{l_1}{l_2}};\quad \eta=-l_1\cdot\frac{-r^2}{1+\dfrac{l_1}{l_2}}=l_1\cdot\frac{r^2}{1+\dfrac{l_1}{l_2}} \qquad (21)$$

$$\text{For } \theta,\ \xi=-\delta\cdot\frac{\tan^2\theta+\dfrac{l_1}{l_2}}{\tan^2\theta-\dfrac{l_1}{l_2}};\quad \eta=0 \qquad (22)$$

The r scale is quadratic and parallel to the x and y scales, while the θ scale falls on the Ξ-axis. The ratio $\frac{l_1}{l_2}$ should be taken negative, otherwise the θ scale will go to infinity for $\tan\theta=\frac{l_1}{l_2}$.

With $\frac{l_1}{l_2}=-\frac{1}{2}$ we obtain the nomogram shown in Fig. 16 which is well suited for values of θ between, say, 15 and 60 degrees. A good chart for small values of θ is obtained by choosing $\frac{l_1}{l_2}=-\frac{1}{25}$ (Fig. 18); in this case the r scale falls nearer to the x scale, the θ scale becomes larger and the small values of θ take up a larger fraction of the length of the scale. This chart can also be used for values of θ near to 90 degrees, since we can substitute $90-\theta$ for θ when x and y are interchanged (the numbers in brackets). Thus, the dotted line in Fig. 18 gives both $6.31\,|\underline{13.5^\circ}=6.13+j\,1.476$ and $6.31\,|\underline{76.5^\circ}=1.476+j\,6.13$.

Equations (20) have the quality that θ remains the same, when r, x, and y are multiplied by the same factor k. By choosing k equal to a suitable power of 10, r can always be reduced to a value between unity and ten (and then the larger one of the numbers x and y will lie between r and $\sqrt{\frac{1}{2}}\,r$). Now, because the scales are quadratic, the accuracy is high at the upper end of the scales but very poor near the origin. Therefore, it is often practical to multiply r, x, and y by a factor 2 or 5 to move the readings of r and the larger one of the quantities x and y toward the upper ends of the scales. This is accomplished by providing two extra sets of numbers along the scales, going from 0 to 5 and from 0 to 20, besides the normal set which goes from 0 to 10 (cf. Ex. 3). In Figs. 16 and 18 these extra numbers are marked by means of horizontal bars, so that corresponding values are obtained by using the isolated numbers, or those above, or those below the bar, choosing the set which gives the best reading. In hand-drawn charts, it is more distinct to use colored numbers, so that corresponding scales have the same color, although the dotted line in Fig. 16 yields alike $0.780+j\,0.329=0.846\,|\underline{22.9^\circ}$ and $3.90+j\,1.645=4.233\,|\underline{22.9^\circ}$ and $15.6+j\,6.58=16.93\,|\underline{22.9^\circ}$ by using respectively the isolated numbers, those above, and those below the bars.

Nomograms for Hyperbolic Sines and Cosines of Complex Arguments

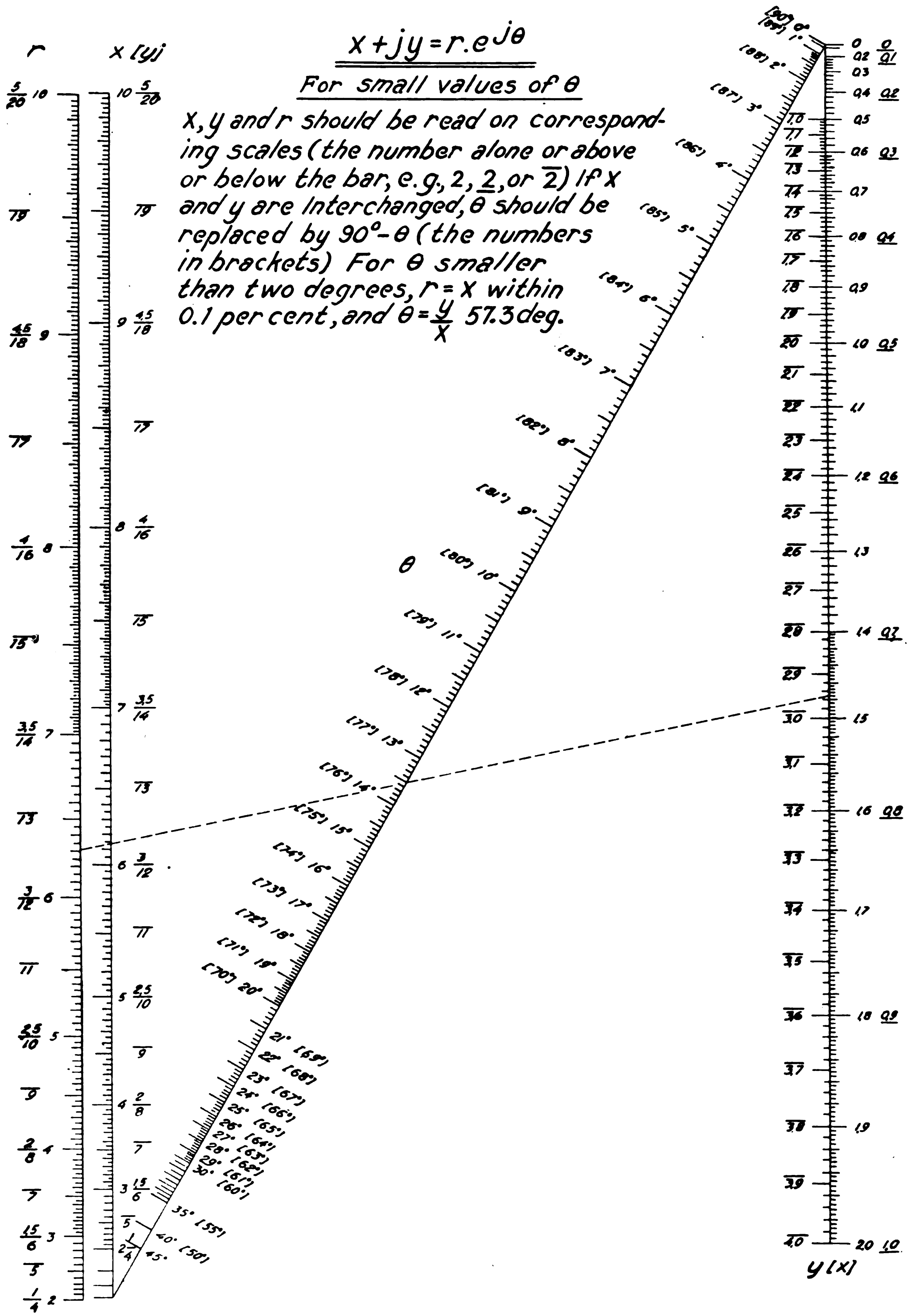
The importance of the hyperbolic functions in electrical engineering has been shown by Professor A. E. Kennelly, who has also published numerical tables and a chart atlas of these functions. The chart atlas is worked out after the principle of points with four coördinates and includes charts of the functions $\frac{\sinh\theta}{\theta}$ and $\frac{\tanh\theta}{\theta}$, which are not suitable for representation in alignment charts.

The hyperbolic sine is defined by

$$\sinh(a+jb)=p+jq \qquad (23)$$

where

$$p=\sinh a\cdot\cos b;\quad q=\cosh a\cdot\sin b \qquad (23a)$$



$x + jy = r.e^{j\theta}$

For small values of θ

x, y and r should be read on corresponding scales (the number alone or above or below the bar, e.g., 2, $\underline{2}$, or $\overline{2}$) If x and y are interchanged, θ should be replaced by 90°−θ (the numbers in brackets) For θ smaller than two degrees, r = x within 0.1 per cent, and θ = $\frac{y}{x}$ 57.3 deg.

Fig. 18. A Nomogram for Determining Vector Relationships Involving Small Values of θ

It is difficult to treat the equations in this form, whereas elimination of b or a between Equations (23a) gives:

$$\left.\begin{aligned} q^2\tanh^2 a+p^2-\sinh^2 a&=0\\ q^2\cot^2 b-p^2-\cos^2 b\quad&=0\end{aligned}\right\}\qquad(23b)$$

These are of the form of Equations (18b) and give the solution immediately. The q and p scales are $u=l_1.q^2$ and $v=l_2.p^2$, and the scales for a and b have the following parametric equations (cf. Equations (9)):

$$\text{(a)}:\quad \xi=-\delta\cdot\frac{\tanh^2 a-\dfrac{l_1}{l_2}}{\tanh^2 a+\dfrac{l_1}{l_2}}\qquad \eta=l_1\cdot\frac{\sinh^2 a}{\tanh^2 a+\dfrac{l_1}{l_2}}\qquad(24)$$

$$\text{(b)}:\quad \xi=-\delta\cdot\frac{\cot^2 b+\dfrac{l_1}{l_2}}{\cot^2 b-\dfrac{l_1}{l_2}}\qquad \eta=l_1\cdot\frac{\cos^2 b}{\cot^2 b-\dfrac{l_1}{l_2}}\qquad(25)$$

Here, $\dfrac{l_1}{l_2}$ should be chosen negative so that ξ_b should not become infinite for finite values of a. It is seen that η_a increases very rapidly, roughly in proportion to $\sinh^2 a$. To obtain good accuracy for all values of a which are of interest in practice (from $a=0$ to, say, $a=4$), it is necessary to construct several charts with different values of $\dfrac{l_1}{l_2}$. The form of the chart for $\dfrac{l_1}{l_2}=-1$ is shown in Fig. 19.

The dotted line indicates how to find $\sinh\left(0.45+j\dfrac{\pi}{4}\right)=0.329+j\cdot 0.780$; and from Fig. 16 is obtained $0.329+j\,0.780=0.846\,\underline{|67.1^\circ}$, if the hyperbolic sine is desired in this form.

If we have

$$\sinh\,(a+jb)=p+jq$$

it follows that

$$\cosh\left[a+j\left(\frac{\pi}{2}-b\right)\right]=q+jp\qquad(26)$$

This shows that nomograms for the hyperbolic cosine are quite similar to the nomograms for the hyperbolic sine, only the p scale will now be called q scale and *vice versa*, and the b graduation will be changed so that $\dfrac{\pi}{2}-b$ is exchanged for the former b.

The sine chart can also be used to obtain hyperbolic cosines. The dotted line in Fig. 19 gives

$$\cosh\left(0.45+j\frac{\pi}{4}\right)=0.780+j\,0.329\ \text{since}\ \frac{\pi}{2}-\frac{\pi}{4}=\frac{\pi}{4}.$$

Of course, the charts are reciprocal so that a and b can be obtained from p and q or even b and q from a and p, etc.

Nomograms for Hyperbolic Tangents of Complex Arguments

Hyperbolic tangents are most easily treated in the form:

$$\tanh\,(a+jb)=r\cdot e^{j\theta}\qquad(27)$$

where:

$$\left.\begin{aligned} r^2&=\frac{\cosh 2a-\cos 2b}{\cosh 2a+\cos 2b}\\ \tan\theta&=\frac{\sin 2b}{\sinh 2a}\end{aligned}\right\}\qquad(27a)$$

These equations can be rewritten in the form of Equations (18b):

$$\left.\begin{aligned} &\sinh^2 2a\cdot(r^2-1)^2+\sin^2 2b\,(r^2+1)^2-4r^2=0\\ &\sinh^2 2a\cdot\tan^2\theta-\sin^2 2b=0\end{aligned}\right\}\qquad(27b)$$

This gives the a and b scales $u=l_1\sinh^2 2a$, $v=l_2\sin^2 2b$, and the following equations for the r and θ scales:

$$\left.\begin{aligned} \text{For } r:\quad \xi&=-\delta\cdot\frac{(r^2-1)^2-\dfrac{l_1}{l_2}\cdot(r^2+1)^2}{(r^2-1)^2+\dfrac{l_1}{l_2}\cdot(r^2+1)^2}\\ \eta&=l_1\cdot\frac{4r^2}{(r^2-1)^2+\dfrac{l_1}{l_2}\cdot(r^2+1)^2}\end{aligned}\right\}\qquad(28)$$

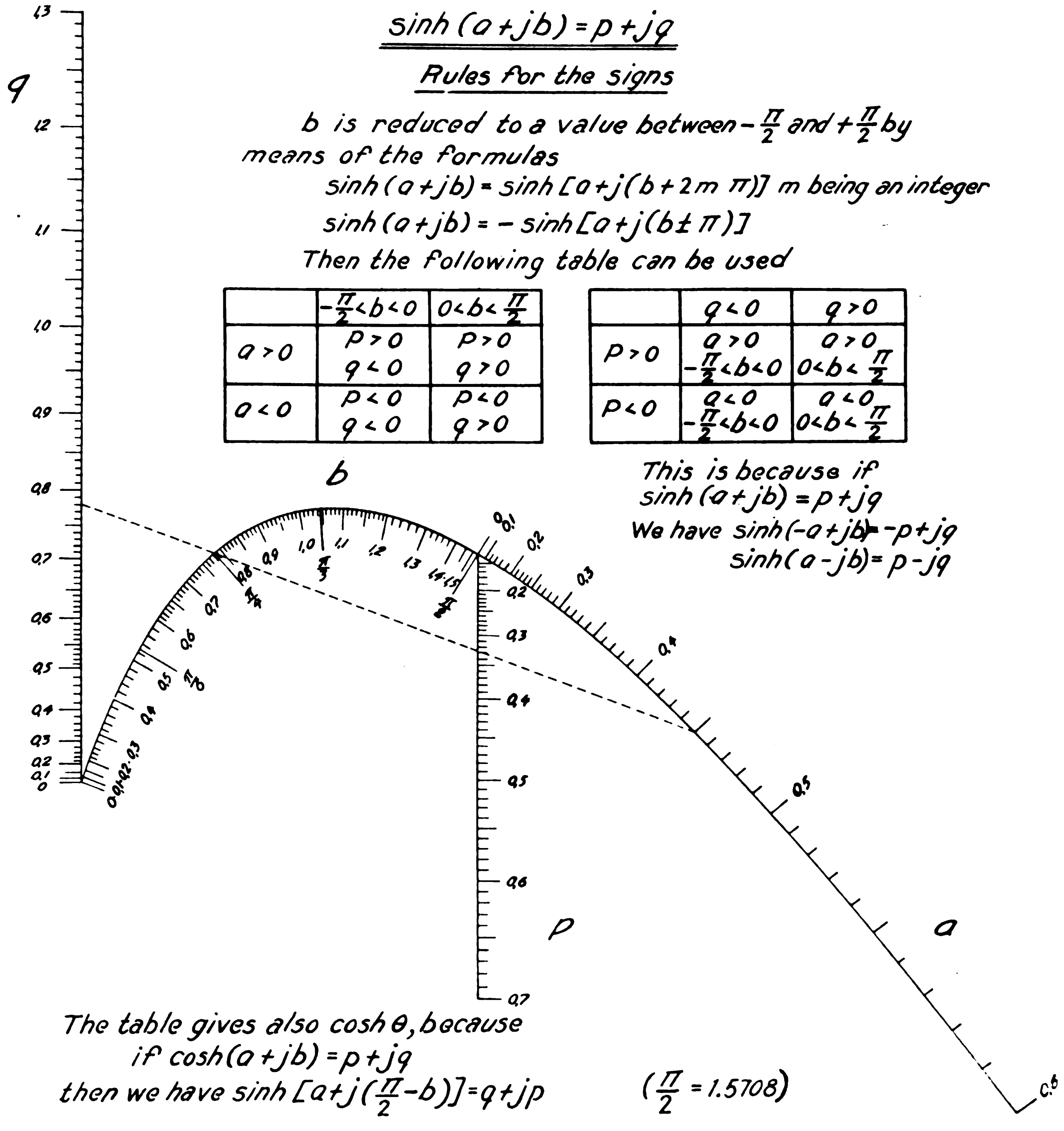
$$\text{For }\theta_1:\quad \xi=-\delta\cdot\frac{\tan^2\theta+\dfrac{l_1}{l_2}}{\tan^2\theta-\dfrac{l_1}{l_2}}\qquad \eta=0\qquad(29)$$

We will now consider the choice of the ratio $\dfrac{l_1}{l_2}$, writing for brevity $\dfrac{l_1}{l_2}=k$. We see that ξ_θ becomes infinite for finite θ, if $k>0$; and besides, it is easily shown that ξ_r and η_r become infinite for finite r, if $-1<k<0$ (the denominator becomes equal to zero for $r^2=\dfrac{1}{1+k}\cdot\left(1-k\pm2\sqrt{-k}\right)$. For these reasons we ought to make k less than -1. But the a scale, $u=l_1\sinh^2 2a$, increases so fast with a that it is only possible to choose $|k|>1$ in charts for very small a.

In all charts except for very small a we must choose $|k|>1$. A difficulty now arises, because if k is positive, the θ scale will go to infinity for finite θ, and if k is negative., the r scale goes to infinity. But this difficulty can be overcome, if we draw charts with both positive and negative k. The two charts with the same numerical value of k can be drawn on the same sheet and be given a common a scale.

Fig. 20 shows such a chart for the case $k=\dfrac{l_1}{l_2}=\pm0.2$. The a scale is common. The scales b_1 and b_2, r_1 and r_2, and $\theta_{1\text{-}2}$ are obtained for $k=+0.2$, and the scales with indices 3 and 4 for $k=-0.2$; their marking is such that scales with the same index give corresponding values of the variables.

There are two b and r scales for k positive and two for k negative. The b scale is $v = l_2 \sin^2 2b$, so that v goes from 0 to l_2 and back to 0 when b varies from 0 to $\frac{\pi}{4}$ and up to $\frac{\pi}{2}$; simultaneously, r goes from $r_{\min}$ to unity and up to $r_{\max}$, where $r_{\min} = \frac{1}{r_{\max}} < 1$. This follows from Equations (27a) which give that if $\tanh(a+jb) = r \cdot e^{j\theta}$, then $\tanh\left[a+j\left(\frac{\pi}{2}-b\right)\right] = \frac{1}{r} \cdot \epsilon^{j\theta}$.



sinh (a+jb) = p+jq

Rules for the signs

b is reduced to a value between $-\frac{\pi}{2}$ and $+\frac{\pi}{2}$ by means of the formulas

$\sinh(a+jb) = \sinh[a+j(b+2m\pi)]$ m being an integer

$\sinh(a+jb) = -\sinh[a+j(b\pm\pi)]$

Then the following table can be used

	$-\frac{\pi}{2}<b<0$	$0<b<\frac{\pi}{2}$
$a>0$	$p>0$ $q<0$	$p>0$ $q>0$
$a<0$	$p<0$ $q<0$	$p<0$ $q>0$

	$q<0$	$q>0$
$p>0$	$a>0$ $-\frac{\pi}{2}<b<0$	$a>0$ $0<b<\frac{\pi}{2}$
$p<0$	$a<0$ $-\frac{\pi}{2}<b<0$	$a<0$ $0<b<\frac{\pi}{2}$

This is because if
$\sinh(a+jb) = p+jq$
We have $\sinh(-a+jb) = -p+jq$
$\sinh(a-jb) = p-jq$

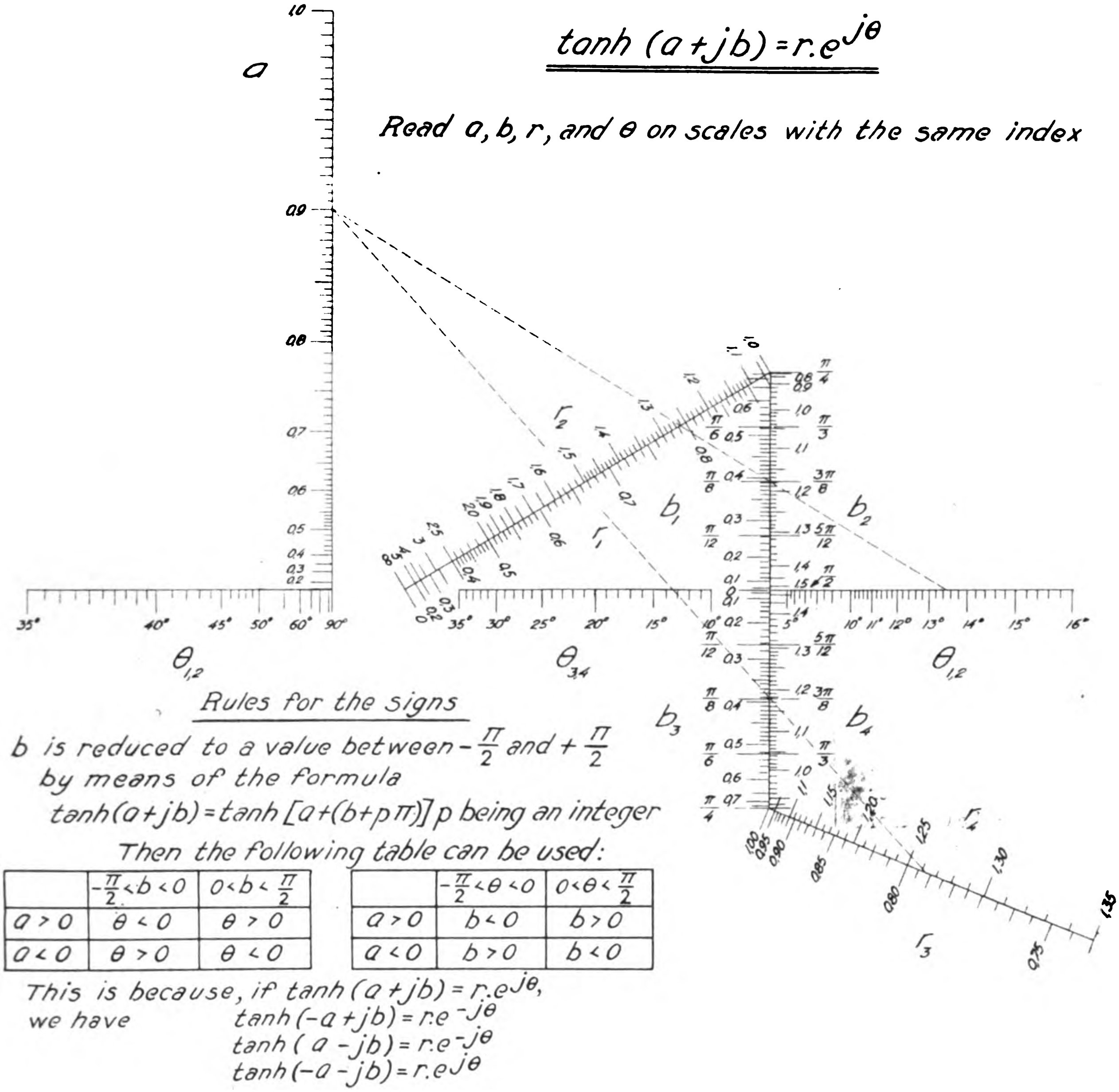
The table gives also cosh θ, because
if $\cosh(a+jb) = p+jq$
then we have $\sinh\left[a+j\left(\frac{\pi}{2}-b\right)\right] = q+jp$ $\left(\frac{\pi}{2} = 1.5708\right)$

Fig. 19. A Nomogram for Equations Involving Complex Hyperbolic Sines and Cosines

The θ scale for $k = +0.2$ is shown for $0 < \theta < 16$ deg. in the right-hand side of the graph, and for 35 deg. $< \theta < 90$ deg. in the left-hand side. It goes to infinity for $\theta = 24.1$ deg. The range 10 deg. $< \theta < 35$ deg. is obtained for $k = -0.2$ but only for $0.74 < r < 1.35$; if r falls outside of this range and 16 deg. $< \theta < 35$ deg., another chart must be used. A series of charts with different k are necessary anyway to cover all desired values of a.

The dotted lines in Fig. 20 give the same readings. From the scales with index 1 or 3 we get

$\tanh\left(0.9+j\frac{\pi}{8}\right)=0.793\,\underline{|13.5^\circ}$, and if we read the scales with index 2 or 4, we get $\tanh\left(0.9+j\frac{3\pi}{8}\right)=1.261\,\underline{|13.5^\circ}$. By means of the nomogram in Fig. 18, we can find $\tanh\left(0.9+j\frac{3\pi}{8}\right)=1.261\,\underline{|13.5^\circ}=1.226+j\,0.295$, if it is desired in this form.



$\tanh(a+jb)=r.e^{j\theta}$
Read a, b, r, and θ on scales with the same index
a
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
35°
40°
45°
50°
60°
90°
30°
25°
20°
15°
10°
11°
12°
13°
14°
16°
$\theta_{1,2}$
$\theta_{3,4}$
$\theta_{1,2}$
b_1
b_2
b_3
b_4
r_1
r_2
r_3
r_4
π/4
π/3
3π/8
5π/12
π/2
π/6
π/8
π/12
1.0
1.1
1.2
1.3
1.4
1.5
1.30
1.25
1.20
1.35
1.15
1.00
0.95
0.90
0.85
0.80
0.75

tanh (a+jb) = r.e^{jθ}

Rules for the signs

b is reduced to a value between $-\frac{\pi}{2}$ and $+\frac{\pi}{2}$ by means of the formula
$\tanh(a+jb)=\tanh[a+(b+p\pi)]$ p being an integer
Then the following table can be used:

	$-\frac{\pi}{2}<b<0$	$0<b<\frac{\pi}{2}$
$a>0$	$\theta<0$	$\theta>0$
$a<0$	$\theta>0$	$\theta<0$

	$-\frac{\pi}{2}<\theta<0$	$0<\theta<\frac{\pi}{2}$
$a>0$	$b<0$	$b>0$
$a<0$	$b>0$	$b<0$

This is because, if $\tanh(a+jb)=r.e^{j\theta}$, we have
$\tanh(-a+jb)=r.e^{-j\theta}$
$\tanh(a-jb)=r.e^{-j\theta}$
$\tanh(-a-jb)=r.e^{j\theta}$

Fig. 20. A Nomogram for Equations Involving Complex Hyperbolic Tangents

The following list contains a few of the numerous books on this subject:

M. d'Ocagne: *Traité de Nomographie*, 2d edition, Paris, 1921 (Gauthier-Villars et Cie).

M. d'Ocagne: *Calcul Graphique et Nomographie*, Paris, 1914 (Octave Doin et fils).

J. Lipka: *Graphical and Mechanical Computation*, New York, 1918 (Wiley & Sons).

S. Brodetsky: *A First Course in Nomography*, London, 1925 (G. Bell & Sons).

A. C. Haskell: *How to Make and Use Graphic Charts*, New York, 1920 (Codex Book Co.).

O. Lacmann: *Die Herstellung gezeichneter Rechentafeln*, Berlin, 1923 (Springer).

The Portable Impulse Generator

By E. J. WADE
Lightning Arrester Engineering Department, Pittsfield Works
General Electric Company

THE impulse generator has been extensively used in the laboratory for a number of years in the production of artificial lightning surges for studying the performance of various types of apparatus under impulse conditions.

Because of the increasing importance of understanding transients which occur in practice, it has been found necessary to make certain studies of traveling-wave phenomena under actual operating conditions. Some of the problems which have been studied are: attenuation of surges on transmission lines, effect of ground wires, effects of terminal apparatus and cables, as well as certain problems in the protection of apparatus against lightning.

To facilitate this work, an impulse generator which is easily moved and which can use as a source of power the ordinary 110-volt lighting circuit, was designed. Two such portable impulse generators have been built by the Lightning Arrester Department of the General Electric Company; one for 400 kv., which has been used for transmission line studies at Pittsfield; the other rated at one million volts, which has been used for field tests in Michigan on the lines of the Consumers' Power Company during the summer of 1929. The following description gives the interesting features incorporated in these generators, also a summary of the operating methods which have been developed.

Description

What type of capacitor to use is the first decision to be made in the design of an impulse generator. Glass plates and oil-paper capacitors are the two types ordinarily used for laboratory generators. For a portable impulse generator, the type which takes the least space and is least subject to breakage would be chosen, other things being equal.

Considering a single glass plate in comparison with an oil-paper unit, the glass plate will be found to occupy about four times as much space for an equal storage of energy as does the oil-paper unit, but when both are built up into banks the difference is about 20 to 1 in favor of the oil-paper capacitors on account of the air spaces necessary between the glass plates when they are connected in the usual manner, *i.e.*, in series. In addition to the space advantage possessed by capacitors of the oil-paper type, they are not subject to breakage. In the light of these advantages, the oil-paper capacitor has been chosen for the portable impulse generators.

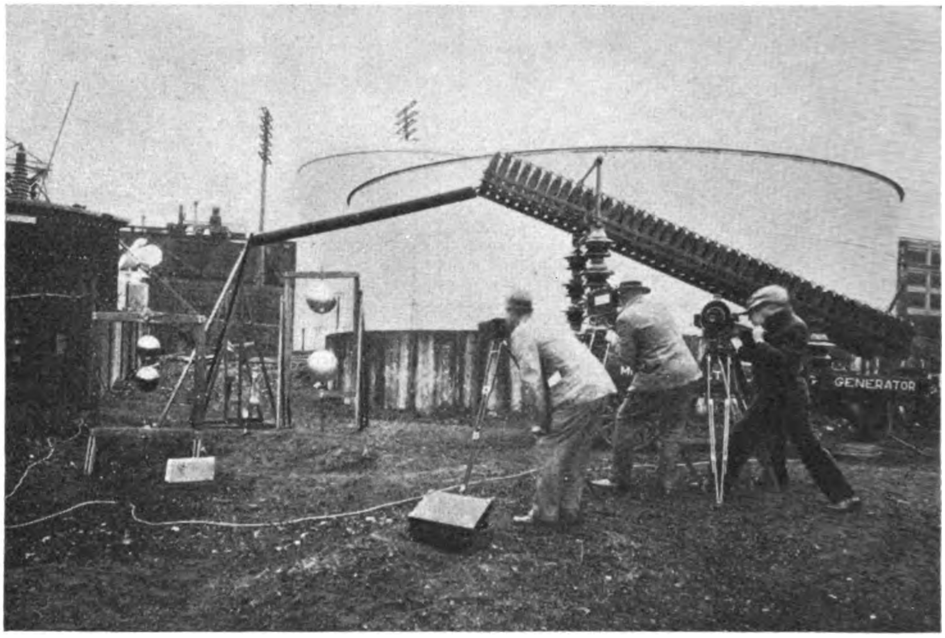


Fig. 1. The Million-volt Impulse Generator First Used on a 66-kv. Line, Showing Application and Construction

The method of mounting the capacitors is largely a matter of individual judgment. However, highway regulations and bridges limit the width and height which may be used, and greatly reduce the number of arrangements which are practical. After considerable study of space considerations, the units were mounted in a straight line along a structure built up of oil-treated maple. For the million-volt generator, 80 capacitors were used arranged in banks of two each. The banks were uniformly spaced, as closely as possible consistent with the necessary insulation.

The voltage per unit was chosen as 25 kv. and the spacing between cases was 1¼ in. The creepage distance over the wood supporting the units must be much greater than this, however, and Fig. 1 shows how this was provided in the design used for the million-volt generator. This design gives great mechanical and dielectric strength with the requisite lightness.

The well-known Marx circuit is ideal for the portable impulse generator because of the comparatively low-voltage charging circuit required. Fig. 2 shows a schematic circuit diagram, wherein it may be noted that all the capacitors are connected in parallel for charging, with the cases at nearly ground potential, which minimizes corona and leakage loss. The charging resistances are the commercial wire-wound enameled type units of 10,000 ohms each. The effect of varying this resistance will be explained later. When the capacitors are all fully charged, the sparking-over or short-circuiting of any one of the discharge gaps will result in the circuit becoming unstable so that all the gaps will spark over. As each succeeding gap receives an increased increment of voltage, the whole operation of changing from a parallel to a series circuit is accomplished in a very short space of time. The sparking of the gaps results in the capacitors being connected in series through the load circuit, which is understood to be the circuit external to the impulse generator. If no external discharge circuit is provided, the generator will discharge through the charging resistances.

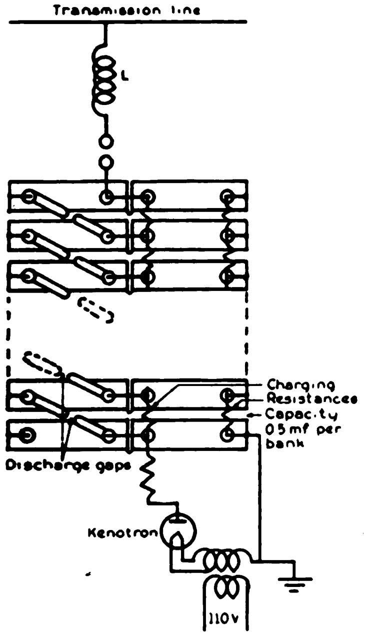


Fig. 2. The Electrical Circuit of the Million-volt Impulse Generator

A small transformer and Kenotron are used to provide the direct current for charging, and since the voltage will be held constant, the Kenotron may be mounted on one bushing of the transformer, and the filament excited from a tap on the high-voltage winding. This eliminates the necessity for a separate insulating transformer for the Kenotron and allows the polarity of the generator to be changed by reversing the high-voltage connections from the charging circuit. Two capacitors in parallel are used to increase the capacity in each 25-kv. bank.

The beam carrying the banks of capacitors is mounted on a truck or trailer either in a fixed position ready for use, or in a movable position which allows it to be lowered for transportation. The fixed position is simpler and consequently more desirable where it can be used. The generator designed for 400 kv. is shown in Fig. 4 as mounted on a trailer with a permanent wooden enclosure.(1) This arrangement is impractical for higher voltages because of the large clearances required which would make the apparatus too large to be readily portable and prevent its being used on the public highways. In the design adopted for the million-volt generator (Fig. 5), the beam, with its banks of capacitors, was arranged to be lifted to the operating position by a motor-driven hoist, as shown in Fig. 6. It is supported in this position by a bar placed across the tops of the post insulators, which allows the wire rope hoisting tackle to be removed as it would short-circuit the insulators. The winch used for hoisting uses a worm drive so that a pawl is not necessary, the motor being reversed for lowering. Limit switches are provided at each end of the travel, and both limit switches are held in the open position when the support is placed under the front end of the beam and the generator is ready for transportation, as shown in Fig. 6. Removable sheet-iron covers built with interlocking sections are used to protect the capacitors when not in use. The overall dimensions of the generator are: length, 18 ft.; width, 6 ft.; and height, 9 ft. The weight is about six tons. The time required to remove the covers and raise the banks of capacitors to the operating position ready for testing, is about 30 min. for two men.

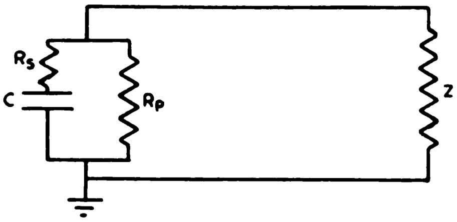


Fig. 3. The Equivalent Circuit of the Impulse Generator

Characteristics

The wave obtained from an impulse generator is controlled by varying the constants of the discharge circuit. The generator itself may be considered as a capacity in series with a variable resistance (R_s) representing the loss in the discharge gaps, together with another resistance in parallel (R_p) representing the charging resistances. This circuit is shown in Fig. 3 in series with a load impedance (Z) which may consist of resistance, inductance, or capacity in any combination. Here, R_p may be approximately represented by the relation

$$R_p = n\ R/2$$

where n is the number of banks in the generator. The term "bank" is used to designate the subdivisions which are used for charging, so that a "bank" may consist of one or more capacitor units, connected either in parallel or in series. The factor R is the resistance of each charging resistor. This relation neglects the fact that the current drawn by the charging resistors from the bank at each end of the generator during discharge is only half as much as from the remaining banks. If the load impedance is low, the effect of the charging resistances may be neglected. In case the load circuit is open, the generator will discharge through the charging resistances, and the resulting wave will be exponential in form with a time constant of $T = C\ (R_p + R_s)$, which is the time for the voltage to be reduced to 37 per cent of its initial value. Here T is expressed in microseconds, C in microfarads, and R in ohms.

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(1) "Cathode Ray Oscillograph Study of Artificial Lightning Surges on the Turners Falls Transmission Line," by K. B. McEachron and V. E. Goodwin, *Trans. A.I.E.E.*, July, 1929, Vol. 48, pp. 953-965.

The calculation of the wave produced by impulse generators may be reduced to the problem of the discharge of a capacity into an impedance which may consist of resistance, inductance, or capacity in any combination. Tests are available which show that calculated waves check the oscillographic results very closely. (2)

For the million-volt generator the capacity is 0.0125 microfarad, which when charged to one million volts will store about 6000 watt-sec. of energy. At the usual rate of discharge, this represents an instantaneous power of about 700,000 kv-a.

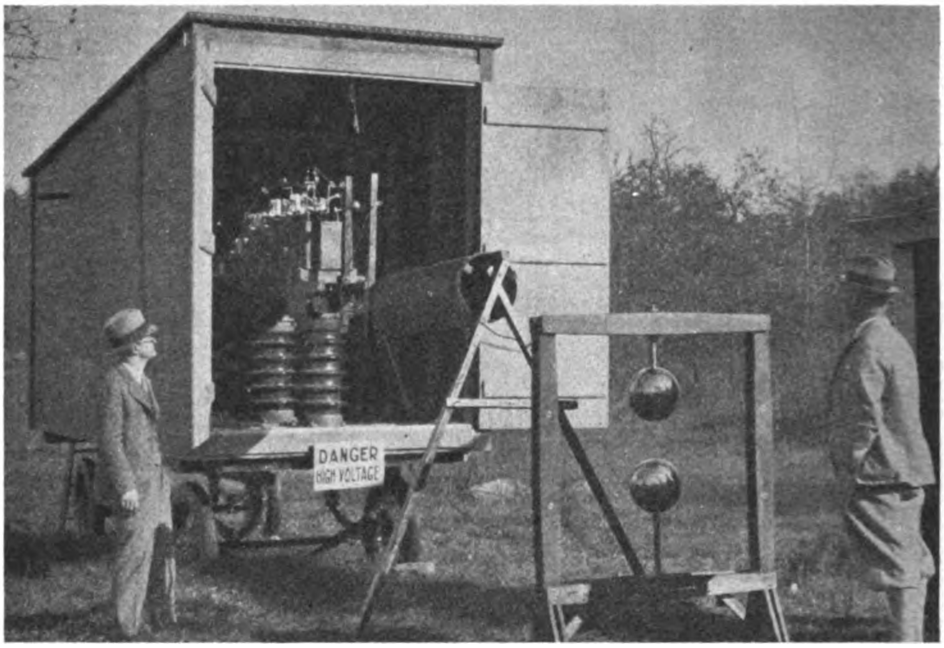

Fig. 4. The Portable Impulse Generator of 400-kv. Rating in Its Permanent Housing

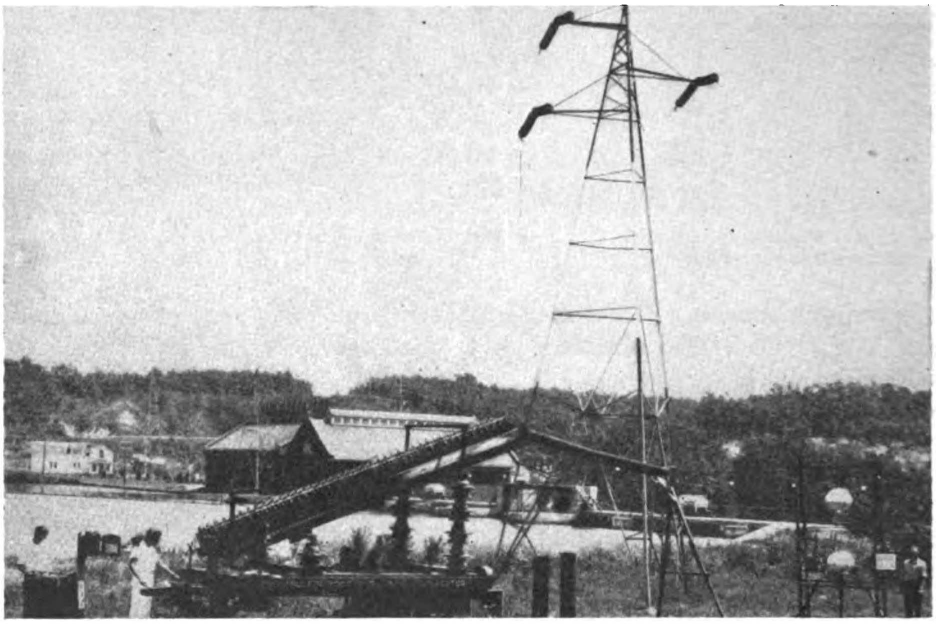

Fig. 5. The Million-volt Impulse Generator in Use on a Transmission Line

Operation

The discharge may be started either by setting one of the discharge gaps so that it will spark when the capacitors become fully charged, or by mechanically short-circuiting one of the gaps, or it may be electrically initiated.

Initiating by Synchronous Switch

The use of a synchronous switch is advantageous for certain kinds of work, particularly where it is desirable to have the impulse occur at a definite point on the 60-cycle wave. A switch was built which not only initiates the transient at the proper time, but also controls the application of potential to all the oscillograph circuits; which include, besides the cathode, sweep, and oscillator circuits, the impulse generator and a calibration circuit.

This synchronous switch is shown in Fig. 7. It is driven by a small self-excited synchronous motor which has a polarity indicator to insure that it falls into step in the right direction. The three contact disks (A) which control the cathode and sweeping circuits are driven directly from the motor. Impulse arm B is driven at double motor speed through spiral gears. Geared to the main shaft, and driven through a clutch are the low-speed disks (D) which turn only when the switch operates and then only for one revolution. The impulse arm C is driven from disks D

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(2) "Reflection of Transmission Line Surges at a Terminal Impedance," by O. Brune, GENERAL ELECTRIC REVIEW, May, 1929, Vol. 32, pp. 258-265.

through a cam (E). When the operating circuit is energized, the clutch moves the low-speed disks through a small angle sufficient to close the impulse generator and oscillator circuits. The disks then stop for one second, during which the impulse generator is charged and the filaments heat up, and then complete the revolution. At the correct time during the completion of the revolution, the cathode, sweep, and calibration circuits are closed and opened, and arm C accelerates so that it passes arm B and allows an initiating impulse to pass at the proper instant; thus the main impulse occurs at the instant the electron beam is crossing the film. The impulse timing can be adjusted by turning a screw which changes the angle of B with respect to the motor shaft. A more complete description of this switch will be published elsewhere.

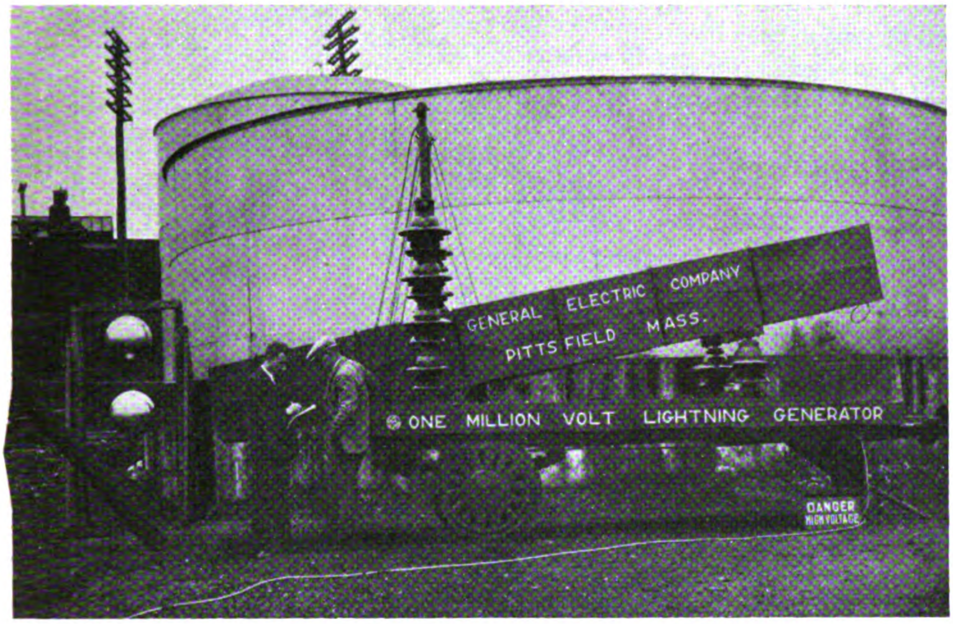

Fig. 6. The Million-volt Generator in Lowered Position, Ready for Transportation

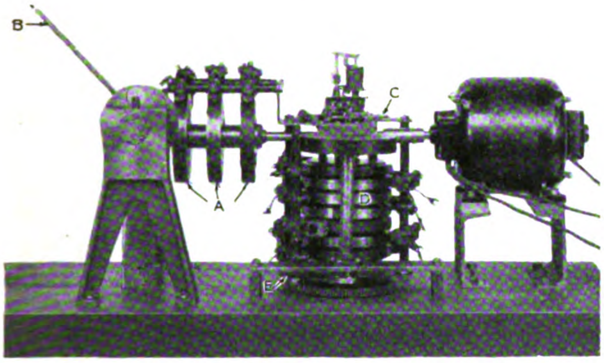

Fig. 7. Synchronous Switch for Use in Recording Impulses on Cathode-ray Oscillograph

Use of Initiating Impulse

When a cathode-ray oscillograph is used to record the impulses, and it is desired to secure an oscillogram of the entire wave front, the oscillograph must be started in operation before the impulse arrives.

Some kind of initiating impulse must be used which may either be controlled by a synchronous switch such as has been described, or the initiating impulse may be used to start the operation of the impulse generator and oscillograph by means of gaps or vacuum tubes. Several methods are available for obtaining and using the initiating impulse, some of which have been described.(3)

The generator may be initiated by an impulse from the oscillograph, or the initiating impulse may originate at the generator. The various methods which have been used will be described in some detail, as the coördination of the impulse generator and oscillograph is of utmost importance.

Initiating by Impulse from the Oscillograph

This method is shown in Fig. 8. A small auxiliary generator (C_1) is charged from the midpoint of the cathode supply capacitors (C_c), and discharges through a resistance (R_1), into C_2, and also into one conductor of the transmission line (L_1). This impulse travels along the line to the point where the impulse generator is located where it initiates the generator by increasing the potential across either gap G_1 or G_2, depending on the polarity. The potential across C_2 is used to bias the middle electrode of gap G, through capacitor C_3. Blocking capacitor C_4 is used in series with L_1, to prevent the impressing of the generator voltage upon the oscillograph circuits. By properly adjusting the values of R_1 and C_2, the operation of the oscillograph can be delayed by a time interval which will permit the transient to be recorded to the best advantage.

Initiating by Impulse from Generator

The circuit just considered may be inverted and the impulse generator used to supply the initiating impulse, as shown in Fig. 9(a). The method of operation is very similar to that shown in Fig. 8. A modification of this circuit having an advantage when a considerable time delay is desired, is shown in Fig. 9(b). Here a Marx circuit is used for the initiating impulse and the two capacitors (C_1 and C_3) act more or less independently after the discharge gaps spark, so that even after C_1 has been discharged by the current taken by L_1, C_3 may still be charging C_2.

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(3)"Lightning Surges Measured," by A. M. Opsahl, *Electrical World*, March 16, 1929, Vol. 93, pp. 535-539.

Use of Transmission Line as Initiating Capacitor

Another method which has been used successfully where great precision of timing is required is shown in Fig. 10. It will be seen that one wire of the transmission line (L_1), is charged to the same potential as the first unit of the impulse generator, being isolated at each end by capacitors C_1 and C_2. When gap G_3 sparks, a wave of discharge will be sent in each direction; that traveling toward the impulse generator will pass through the capacitor C_1 and increase the potential across G_1, initiating the generator, while the other wave will initiate the oscillograph operation.

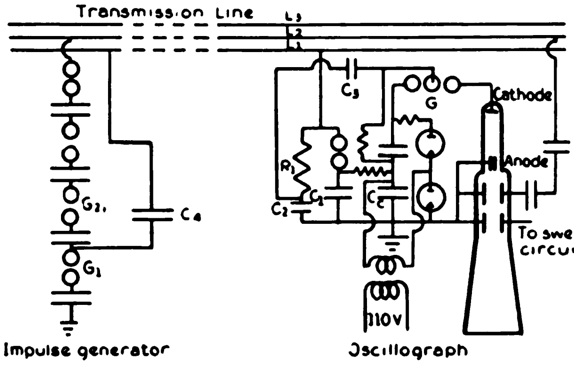

Fig. 8. Circuit Employed in Initiating Impulse from the Oscillograph

The time lag between the arrival of the initiating impulse at the oscillograph on line L_1 and the arrival of the main impulse on line L_2 will be determined by the location of gap G_3 on the line. This method is inherently accurate because it does not depend on the time of sparking of gaps with the consequent error due to time lag; and because the initiating impulse at the generator and oscillograph has a very steep wave front which starts the circuits into operation very quickly.

One method of modifying this circuit, so that the occurrence of the discharge may be manually controlled, is shown by the dotted lines in Fig. 10. Instead of connecting gap G_3 directly to ground, line L_1 may be connected to another line (L_3) at the point where gap G_3 would normally be placed and the gap G_3 located either at the impulse generator or at the oscillograph.

Conclusion

This article, in brief, is a description of two impulse generators, one rated at 400 kv., and the other at 1000 kv. together with a consideration of some of the factors affecting the design of impulse generators. The 400-kv. generator has been used for the study of traveling waves on transmission lines, and for making tests on the action of choke coils at Pittsfield, (Mass.). The million-volt generator was used for studying the action of lightning arresters on a live line, and it is believed that in May, 1929, the first application of impulses to a 66-kv. line was made. This generator was also used for extensive transmission line tests in Michigan during the summer of 1929, some of which have been recently described.⁽⁴⁾

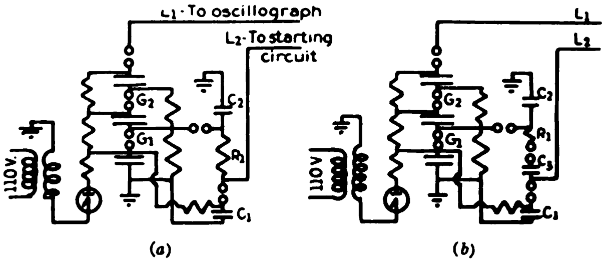

Fig. 9. Circuits Employed for Initiating Impulse from Generator. Circuit (a) is the inversion of that in Fig. 8; (b) is a modification of (a) for securing time delay

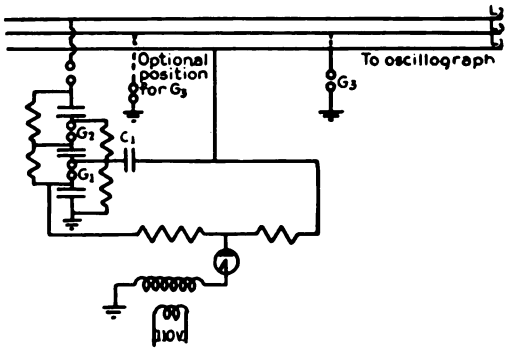

Fig. 10. Circuit for Initiating Impulse from the Transmission Line

A synchronous switch for use with cathode-ray oscillographs is described, and several circuits are given showing different methods of supplying the initiating impulse for coördinating the operation of the impulse generator and oscillograph.

When the ease with which impulse generators for high voltages may be constructed and operated becomes more widely known, more uses will be found for them, such as making factory tests, checking the condition of lightning arresters in service, and making tests on apparatus which cannot be conveniently brought to the laboratory.

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(4) At the Midwinter Convention of the A.I.E.E. in New York City, Jan. 27-31, 1930. This will appear in a forthcoming article by K. B. McEachron, J. G. Hemstreet, and W. J. Rudge in the General Electric Review.—Editor

Lightning Investigations on Transmission Lines

By **W. W. LEWIS** and **C. M. FOUST**
Central Station Engineering Department **General Engineering Laboratory**
General Electric Company

(A paper presented at the Winter Convention of the A.I.E.E. at New York, January, 1930)

Great progress has been made toward a solution of our lightning problems. The surge voltage investigations of 1926 and 1927 are reviewed and data are given concerning the work carried out in 1928 and 1929.—EDITOR

A "SYMPOSIUM on Surge Voltage Investigation," covering mainly the work done in 1926 and 1927, was presented at the annual convention of the A.I.E.E., at Denver, in June, 1928.(1)

Tentative conclusions were drawn as to polarity and magnitude of surges, wave-shape and attenuation, and it was stated that in the coming year special efforts would be made to obtain data on wave-shape, attenuation, effect of ground wires and effect of lightning arresters and choke coils.

Two years' additional data have now been accumulated and we can answer some of the questions which were unanswered at the Denver Convention.

In 1928 work was continued on the Pennsylvania 220-kv. interconnected system; the Consumers' Power Co. 140-kv. system; the Ohio Power Co.'s 132-kv. system and the New England Power Co.'s 110-kv. system. The cathode-ray oscillograph was introduced and a laboratory installed at Wallenpaupack to obtain oscillograms of the surges produced on transmission lines by natural lightning.

Mr. McEachron also began in 1928 his work on the Turners Falls 66-kv. transmission line, in the course of which he placed artificial lightning surges up to 400 kv. on the transmission line and studied their effects by means of the cathode-ray oscillograph.(2)

In 1929 the work was discontinued on the New England Power system, but continued on the Pennsylvania, Consumers' and Ohio systems. A second cathode-ray oscillograph was installed at Wallenpaupack and connected to an antenna 300 ft. long, 50 ft. above the ground. A cathode-ray oscillograph was installed at Newcomerstown on the Ohio system and connected to the 132-kv. line. Mr. McEachron continued his work with artificial lightning on the Turners Falls system and in addition conducted an extensive investigation with a 1000-kv. portable lightning generator on a 70-kv. line of the Consumers' Power Co. in Michigan. The artificial lightning investigation was described in a paper at the winter convention.(3)

In the 1929 investigation new instruments were introduced as follows: Lightning stroke recorders, field intensity recorder and rate of change of field intensity recorder.

In the present paper the 1928 and 1929 work will be described and an effort will be made to summarize the present status of the investigation and to outline the future work.

(*1*). Crest Values of Surge Voltages due to Lightning and Switching

Lightning

In Table I are listed the maximum voltages due to lightning on three systems for the years 1926, 1927, 1928, and 1929, as measured by the surge voltage recorder. (The locations of the surge voltage recorders are indicated in diagrams in companion papers(4) and in the Denver papers previously mentioned.(1)) The voltages are given both in kilovolts and in the number of times normal crest line-to-neutral voltage. For comparison are given also the approximate insulator impulse flashover values as measured by the five-microsecond "Pittsfield Wave." This wave has the following general description:

It rises to its crest value in about ¼ microsecond, then decreases to 50 per cent crest value in about five microseconds.(5) The values given are for flashover on the tail of the wave.

In the case of the Pennsylvania Power & Light Company's system the line under investigation is that formerly known as the Wallenpaupack-Siegfried line. (Now known as Wallenpaupack Tap and Siegfried-Roseland Line.) The length is 65 miles.

The conductors are arranged horizontally. Up to the year 1929 the insulation consisted of 14 disks spaced 5¾ in. apart with grading rings at the line end only. In the year 1929, two additional disks were added on the outside conductors for a distance of 40 miles from the Wallenpaupack end. The conductors are 795,000 cir. mils; they are made of aluminum, reinforced with steel. There are two 184,000-cir. mil overhead ground wires, of similar construction. The ground wires extend for 20 miles from the Wallenpaupack end and five miles from the Siegfried end. They were installed in 1927.

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(1) "Symposium on Surge Voltage Investigation," by W. W. Lewis, E. W. Dillard, J. G. Hemstreet and J. R. Eaton, P. Sporn, and N. N. Smeloff, *Trans. A.I.E.E.*, Vol. 47, No. 4, 1928, page 1111.

(2) "Cathode Ray Oscillograph Study of Artificial Lightning Surges on the Turners Falls Transmission Line," by K. B. McEachron and V. E. Goodwin, *Trans. A.I.E.E.*, 1929, Vol. 48.

(3) "Study of Traveling Waves on Transmission Lines with Artificial Lightning Surges," by K. B. McEachron, J. G. Hemstreet, and W. J. Rudge, part of symposium at the Winter Convention in New York City, on the subject of Lightning Investigation.

(4) "Lightning Investigation on the Ohio Power Co. System," by Philip Sporn and W. L. Loyd, "Lightning Investigation on the 220-kv. System of Pennsylvania Power & Light Co.," by N. N. Smeloff and A. L. Price.

(5) "Progress in Lightning Research in the Field and in the Laboratory," by F. W. Peek, Jr., Midwinter Convention A.I.E.E., 1929.

On the Ohio Power Company's system the lines under investigation are the two circuits arranged vertically on the same towers, extending from Philo to Canton, a distance of 73 miles. The insulation consists of 11 disks on top and in the middle and 10 disks on the bottom conductors; all are spaced 4¾ in. apart. The strings are equipped with grading rings at the line end only. The conductors are 336,400 cir. mils, made of aluminum, reinforced with steel. They extend the total length of the line. There is one 159,000-cir. mil overhead ground wire of similar construction.

On the New England Power Co. system there are two circuits, with all conductors arranged horizontally. The conductors are 4/0 copper cable (212,000 cir. mils). Previous to 1928 there was one ground wire, and in 1928 a second ground wire was added. The ground wires are of $\frac{7}{16}$-in. steel cable.

Prior to 1928 all conductors were insulated with eight disks spaced five in. apart, with no grading rings. In 1928 the insulation was increased to ten disks on the two outside conductors and to nine on the conductors adjacent to the two outside ones, while eight disks were retained on the two innermost conductors. Grading rings were added to all strings at both line and ground ends.

It will be noted from Table I that maximum voltages have been recorded which exceed the approximate impulse insulator flashover kv. This may mean that occasionally actual surges have required a much shorter time to reach flashover than with the "Pittsfield Wave" on which the assigned impulse flashovers are based. However, the accuracy of voltage registration by means of Lichtenberg figures should be kept in mind in considering these extreme registrations.(6)

In Table II are given the height of line at the tower and the average height of the top conductor, also the kilovolts per foot of height, as measured by surge voltage recorders in 1926-27-28-29.

On the special antennas used in connection with the field intensity recorder a potential gradient of 280 kv. per meter (85.5 kv. per ft.) was measured. This is beginning to approach the figure of 100 kv. per ft., which it has been customary to use as the gradient possible in the worst case. It is probable that the gradient on the transmission line is set by the flashover of the line insulators, and that this gradient will increase as the line insulation is increased.

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(6) "Measurement of Surge Voltages on Transmission Lines due to Lightning," by E. S. Lee and C. M. Foust, *Trans. A.I.E.E.*, Vol. 46, 1927, p. 339.

TABLE I

MAXIMUM VOLTAGE CAUSED BY LIGHTNING, AS MEASURED BY SURGE VOLTAGE RECORDER

System	Rated Voltage (Kv.)	Normal Voltage Crest (Kv. Line to Neutral)	Approximate Insulator Flashover Impulse (Kv.) (1)	MAXIMUM CREST VOLTAGE CAUSED BY LIGHTNING (KV.)				NUMBER OF TIMES NORMAL VOLTAGE			
				1926	1927	1928	1929	1926	1927	1928	1929
Pennsylvania Power and Light Co.	220	180	1950 2210 (2)	2100+	2100	2700+	2400+	11.7	11.7	15.0	13.3
Ohio Power Co.	132	108	1180 1280 (3)	...	1200	1640	1545	...	11.1	15.2	14.3
New England Power Co.	110	90	1025 1150 } 1280 } (4) 1400 }	240	900	740	...	2.7	10.0	8.2	...

(1) Based on five-microsecond Pittsfield Wave.
(2) Part of line changed from 14 to 16 disks. (spaced 5¾ in.) in 1929.
(3) Bottom conductor had ten disks (spaced 4¾ in.), middle and top conductors 11 disks, for all years.
(4) Up to 1928 all conductors had eight disks (spaced five in.); in 1928 outside conductor had ten disks and grading rings, next conductor nine disks and rings and inside conductor eight disks and rings.

NOTE.—Maximum voltage on Ohio Power system in 1927 recorded on middle conductor, in 1928 and 1929 on bottom conductor.

TABLE II

HIGHEST MEASURED VOLTAGE CAUSED BY LIGHTNING IN KILOVOLTS PER FOOT, BASED ON AVERAGE HEIGHT OF CONDUCTOR

	Height of Line at Tower (Feet)	Average Height of Conductors (Feet)	KV. PER FT. OF HEIGHT			
			1926	1927	1928	1929
Pennsylvania Power and Light Co.	66	52	40	40	52	46
Ohio Power Co.	59*	48*	..	20	34	32
New England Power Co.	49	41	6	22	18	..

* Bottom conductor.

In Fig. 1, 2 and 3 are plotted the surge voltages caused by lightning during the years 1927, 1928, and 1929 respectively. The abscissas represent times normal crest line-to-neutral voltage, and the ordinates represent percentage of the total number exceeding the value indicated by the abscissas.

The curves for the Pennsylvania system show a much larger percentage of high surges than for the Ohio and New England systems. The tendency of the Pennsylvania system to record higher voltages may be due to some property of the line insulation and construction (the Pennsylvania line is more highly insulated than the others and has ground wires over only a portion of the line). It may be caused by the chance of more strokes and strokes of great severity near the line, or it may be due to the fact that recorders are placed closer together over the entire line than on the other systems.

The year 1929 shows a tendency for the number of surge voltages of high magnitude on the Pennsylvania system to be much greater than in previous years. In fact, in the year 1929 there were 14 surges over 13.3 times normal (2400 kv.) out of a total of 45 surges which exceeded 300 kv. The indication from the measurements and from line operation is that this line is in an unusually severe lightning territory.

Switching

Table III gives the maximum voltage caused by switching, as measured during the years 1926, 1927, 1928, and 1929, also the approximate 60-cycle flashover of the line insulators.

In spite of the high values occasionally reached, the majority of all switching surges are less than 3.5 times normal. It is probable that slightly more than the 60-cycle flashover voltage is required to flash over during a switching surge (estimated

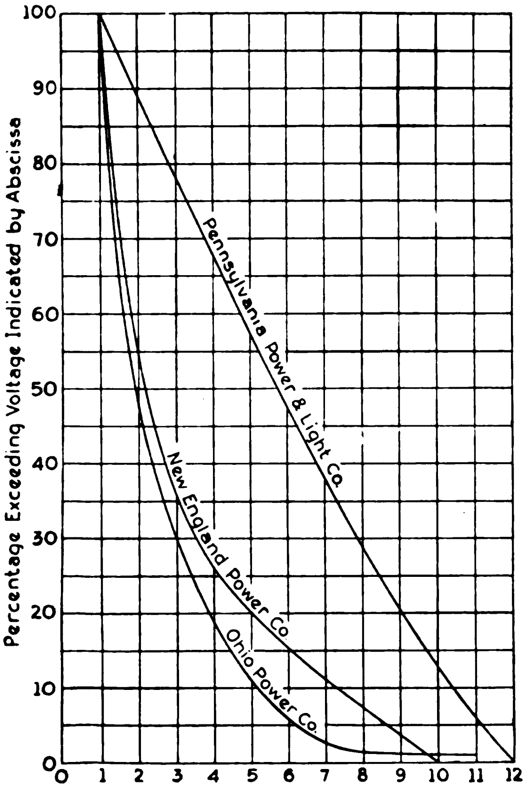

Fig. 1. Values of Surge Voltages Caused by Lightning, 1927

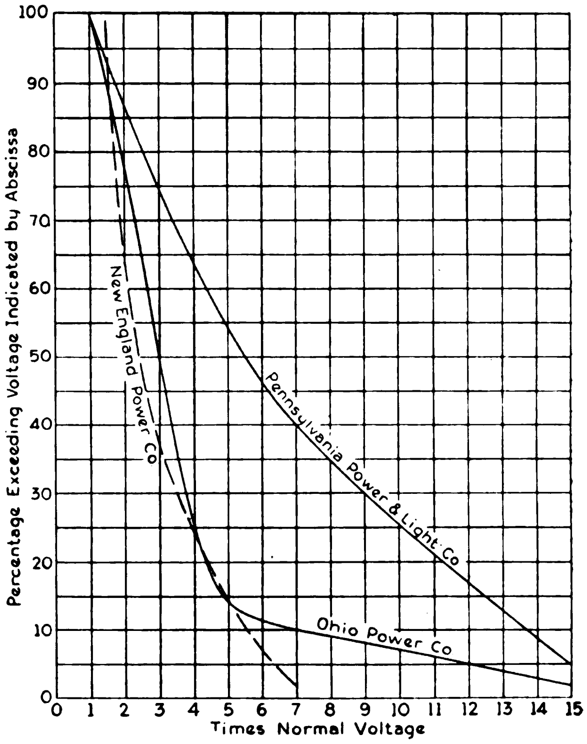

Fig. 2. Values of Surge Voltages Caused by Lightning, 1928

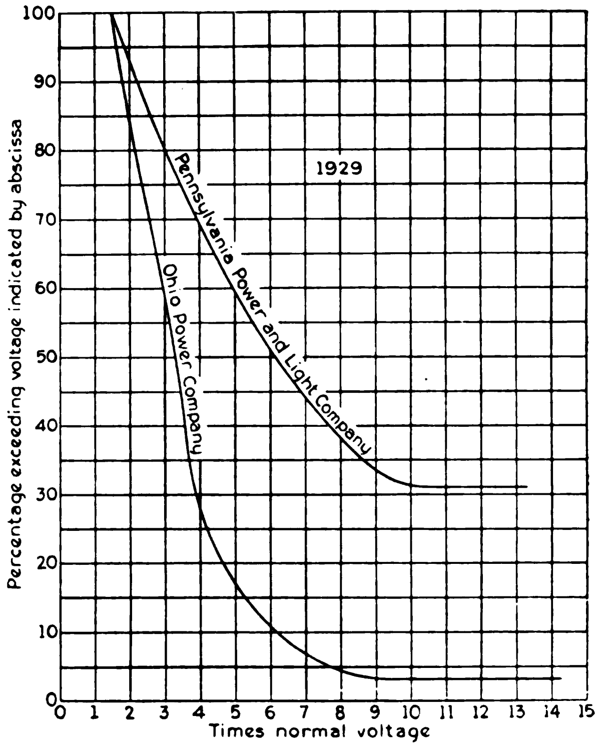

Fig. 3. Values of Surge Voltages Caused by Lightning, 1929

impulse ratio 1.2). It is apparent from the data that the 60-cycle flashover of line insulation cannot be neglected, especially if the insulators are liable to be subjected to rain at the time of switching.

In general it was noted that deënergizing was somewhat more severe than energizing. For example, on the Ohio system in 1929, there were measured 20 surges caused by deënergizing with a maximum value of 4.9 times normal, and only three surges caused by energizing with a maximum of 2.8 times normal. Switching the load on and off gave a very mild overvoltage disturbance (of the magnitude of 1.2 times normal on the Ohio Power system.)

(2). Tripouts Caused by Lightning, and Flashed Insulator Strings

The number of surges caused by lightning, as measured by the surge voltage recorder, is given in Table IV for the years 1926, 1927, 1928, and 1929 for the three systems under discussion, also the number of line tripouts. The data on the number of surges are given for the portion of the year indicated in the last column of the table, while the data for the tripouts cover the whole year. It is evident that there are many more surges recorded than there are tripouts.

The data indicate that for the four years there was an average of about 29 tripouts per hundred miles, per year, on the Pennsylvania system, 14 on the Ohio system, and 24 on the New England system.

Data compiled on these systems also show that there are as many as one to five insulator strings or assemblies flashed over for each tripout. In other words, each stroke which causes a flashover usually affects more than one string or assembly, either on the same tower or on adjacent towers.

Statistics also indicate that where there are two circuits on a tower, from five to 25 per cent of the strokes affect insulator strings on both circuits.

In case of circuits with conductors arranged horizontally, or two circuits with some horizontal distance between them, statistics seem to indicate that the conductor or circuit on the side from which the storms generally approach suffers the greatest number

TABLE III

MAXIMUM VOLTAGE CAUSED BY SWITCHING AS MEASURED BY SURGE VOLTAGE RECORDER

System	Rated Voltage (Kv.)	Normal Voltage Crest (Kv. Line to Neutral)	Approximate Insulator Flashover 60 Cycles (Kv. Crest)	MAXIMUM CREST VOLTAGE DUE TO SWITCHING				NUMBER OF TIMES NORMAL VOLTAGE			
				1926	1927	1928	1929	1926	1927	1928	1929
Pennsylvania Power and Light Co.	220	180	1025 1150 (1)	630	720	845	450	3.5	4.0	4.7	2.5
Ohio Power Co.	132	108	650 700 (2)	. . .	560	595	530	. . .	5.2	5.5	4.9
New England Power Co.	110	90	565 510 } (3) 565 } (3) 615 } (3)	207	360	370	. . .	2.3	4.0	4.1	. . .

(1) Part of the line changed from 14 to 16 disks (spaced 5¾ in.) in 1929.

(2) Bottom conductor had ten disks (spaced 4¾ in.): middle and top conductors, 11 disks, for all years.

(3) Up to 1928 all conductors had eight disks (spaced 5 in.); in 1928 outside conductor had ten disks and grading rings, next conductor nine disks and rings, and inside conductor eight disks and rings.

TABLE IV

NUMBER OF SURGES AND NUMBER OF TRIPOUTS CAUSED BY LIGHTNING

System	Rated Voltage Kv.	Line Length Miles	NUMBER OF SURGES CAUSED BY LIGHTNING MEASURED BY SURGE VOLTAGE RECORDERS				NUMBER OF LINE TRIPOUTS CAUSED BY LIGHTNING				Period During Which Surge Voltages Were Measured
			1926	1927	1928	1929	1926	1927	1928	1929	
Pennsylvania Power and Light Co.	220	65	33	48	28	45	16	7*	14	38	1926 July 20—Oct. 4 1927 Mar. 12—Nov. 2 1928 April 15—Oct. 1 1929 April 17—Oct. 1
Ohio Power Co.	132	73	. .	166	46	31	15	4	12	11	1927 May 11—Oct. 16 1928 April 29—Oct. 20 1929 May 6—Oct. 1
New England Power Co.	110	74	14	104	47	. .	11	43	5	13	1926 July 28—Sept. 12 1927 June 6—Oct. 10 1928 June 23—Oct. 8

* Line out of service two months during lightning season, installing ground wires.

NOTE.—Tripouts are given for the whole year while surges were recorded for only a portion of the year as noted in last column. Ohio Power and New England tripouts are for two circuits.

of insulators damaged. For example, on the Pennsylvania Power and Light Co. 220-kv. line from Wallenpaupack to Siegfried, during the four years 1926, 1927, 1928, and 1929, there were 115 insulator strings flashed over on the west, or storm, conductor, 51 on the middle, and 97 on the east conductor.

On the Hartford Electric Light Co. system, a 66-kv. line 33 miles long, with two circuits arranged vertically on the same towers, ran generally northwest. The southwest circuit is on the windward side and the side towards approaching thunderstorms. Three years' operation of the line showed that trouble from insulator flashover and failure was more than twice as great on the southwest circuit as on the other or lee circuit.

(3). Wave Front and Wave Shape

An analysis of 150 Lichtenberg figures obtained by the surge voltage recorder in 1927, on three different systems, gave the following rough summary as to the duration of the wave front of the surges producing the figures: One surge only less than one microsecond, about 20 per cent of all surges between one and ten microseconds, about 20 per cent between ten and 100 and about 60 per cent over 100 microseconds.

A cathode ray oscillograph was installed in the lightning laboratory on the Pennsylvania System at Wallenpaupack (Tower 1–3) during the latter part of the 1928 season, and one oscillogram was obtained of a lightning surge.(7) The surge was positive in polarity, rose to maximum in eight microseconds, reduced to 50 per cent of that value in 17 microseconds, and to zero in 35 microseconds. The crest voltage of the main wave was approximately 600 kv. See Fig. 5(A). At a point 17 miles from the laboratory a value of 2100 kv. was measured by the surge voltage recorder.

In 1929 the cathode-ray oscillograph installation (Fig. 4) was continued at Wallenpaupack and in the course of the season 95 surges were recorded. Of these, there were 50 surges under 100 kv., 30 between 100 and 300 kv., and 15 over 300 kv. at the laboratory.

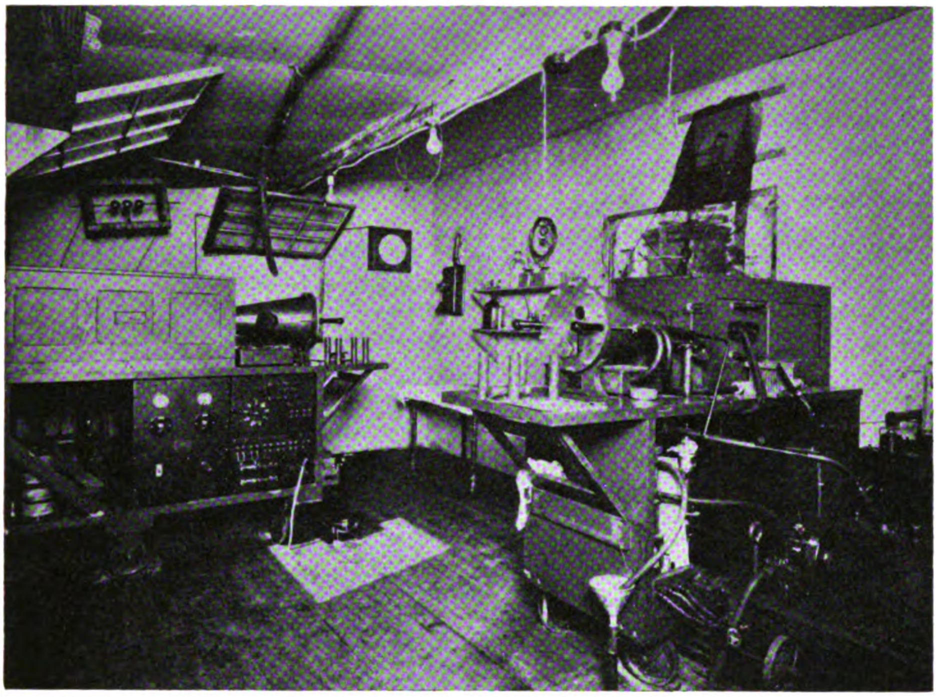

Fig. 4. Interior View of Wallenpaupack Laboratory, Showing Two General Electric Portable Cathode-ray Oscillographs

Table V summarizes the data for the oscillograms with voltage magnitudes between 100 and 300 kv. These are typical of all surges recorded in this voltage classification.

The oscillograms obtained indicate that the surges have various wave-shape characteristics. For this reason, under the column heading, "Time in Microseconds," four columns are given: First, the time consumed in the initial voltage rise. In several cases this is given between zero and a definite time value, the portion of the wave previous to this time not being recorded; second, the time required to reach the maximum voltage recorded; third, the time between the beginning of the surge and half the maximum voltage value on the tail of the wave; and, fourth, the time duration of the first loop of the wave.

In Table VI are summarized the data for the 15 oscillograms with voltage magnitudes exceeding 300 kv. It will be noted that the voltage magnitudes

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(7) "Transmission Line Insulation and Field Tests Pertaining to Lightning," W. W. Lewis, GENERAL ELECTRIC REVIEW, July, 1929, p. 364.

TABLE V

CATHODE-RAY OSCILLOGRAMS 100 TO 300 KV.—YEAR 1929

PENNSYLVANIA POWER & LIGHT CO.

Oscillogram CD Number	Kv. Max.	Polarity of First Loop	Nature of Wave	TIME IN MICROSECONDS TO REACH				ORIGINAL DISTURBANCE ON LINE	
				At Least 75 Per Cent of Max. Voltage Recorded	Max. Voltage Recorded	50 Per Cent Max. on Tail of Wave	Zero of First Loop	Distance in Miles from Oscillograph	Kv. Measured Near Origin
901240	300	Pos.	Osc.	8	8	24	45	?	?
901190	280	Pos.	Osc.	4	4	11	20	32	610
901187	260	Pos.	Uni.	0-1	5	26	45+	0-3	300
901200	260	Pos.	Osc.	5	5	27	36	?	?
901203	260	Pos.	Osc.	2	5	25	35	44	2400
901235	260	Pos.	Osc.	0-2	19	40	42	61	2400
901191B	250	Pos.	Osc.	0-1.3	3	5.5	9.5	?	?
901178	245	Pos.	Uni.	0-1.2	0-1.2	22	33+	?	?
901245	210	Pos.	Uni.	0-5	0-5	85+	85+	17	720
901276	210	Pos.	Uni.	9	9	10+	10+	?	?
901283	205	Pos.	Uni.	0-3.5	0-3.5	13	89+	0-3	300
901183	180	Pos.	Osc.	5	5	23	32	?	?
901189A	180	Pos.	Uni.	0-1.5	5	20	45+	?	?
901197	180	Pos.	Osc.	0-1	6	27	35	?	?
901199	180	Pos.	Osc.	2.5	4.5	18	26	?	?
901254	180	Pos.	Osc.	0-17	0-17	28	40	48	1100
901204	170	Pos.	Uni.	0-1	20	43+	43+	44	2400
901179	160	Pos.	Osc.	0-1	5	13	24	?	?
901222	155	Neg.	Osc.	17	17	24	31	40	2400
901198	150	Neg.	Uni.	0-1.5	4	45+	45+	?	?
901189B	140	Neg.	Uni.	0-1.5	20-28	45+	45+	?	?
901202	140	Neg.	Uni.	4	32	38	43+	44	2400
901214	135	Neg.	Osc.	0-2	0-2	6	10	?	?
901201A	130	Pos.	Osc.	3	3	11	33	?	?
901295	130	Pos.	Uni.	0-1	20	81+	81+	?	?
901230C	120	Neg.	Uni.	0-2	80	156+	156+	?	?
901241	120	Pos.	Osc.	6	6	12	15	?	?
901292	110	Pos.	Uni.	0-4.5	0.4-5	9.5	14	3	2400
901226	105	Neg.	Uni.	0-1.5	40	96+	96+	?	?
901252A	105	Pos.	Uni.	0-2	82	82+	82+	?	?

Osc.—Oscillatory, highly damped. Uni.—Unidirectional. ? —Point of origin of surge not definite from surge voltage recorder records.

TABLE VI

CATHODE-RAY OSCILLOGRAMS OVER 300 KV.—YEAR 1929

PENNSYLVANIA POWER & LIGHT CO.

Oscillogram CD Number	Kv. Max.	Polarity of First Loop	Nature of Wave	TIME IN MICROSECONDS TO REACH				ORIGINAL DISTURBANCE ON LINE	
				At Least 75 Per Cent of Max. Voltage Recorded	Max. Voltage Recorded	50 Per Cent Max. on Tail of Wave	Zero of First Loop	Distance in Miles from Oscillograph	Kv. Measured Near Origin
901180	1260	Neg.	Osc.	3.3	3.3	3.7	4	10	2400
901194	810	Neg.	Osc.	36	36	?	37	21	1360
901193	740	Pos.	Osc.	7	7	16	22	0-3	690
901201B	740	Neg.	Uni.	6.5	6.5	43+	43+	0-3	640
901285	630	Pos.	Osc.	11	11	20	29	0-3	860
901191A	600	Neg.	Uni.	0-1.6	4	14.5	45+	0-3	550
901272	600	Neg.	Uni.	0-7.5	0-7.5	69+	69+	40	2400
901188	530	Pos.	Osc.	3	7-8	18	24	0-3	580
901275	500	Pos.	Osc.	0-8	0-8	32	45	0-3	470
901249	390	Pos.	Osc.	6	6	14	18	0-27	480
901251	390	Pos.	Osc.	6	6	35	55	?	?
901185	360	Pos.	Uni.	0-1.6	4	45+	45+	0-3	400
901186	330	Pos.	Osc.	1.6	1.6	16	29	0-3	300
901229	330	Neg.	Uni.	?	?	12	75	58	2400
901231	330	Pos.	Osc.	?	?	18	25	?	?

Osc.—Oscillatory, highly damped. Uni.—Unidirectional. ? —Point of origin of surge not definite from surge voltage recorder records.

in this classification range from 330 to 1260 kv. The wavefront ranges from 1.6 to 36 microseconds. Two of the oscillograms obtained could not be analyzed for wavefront, because of improper adjustment in the oscillograph arrangement. The total duration varied from four to 75 microseconds. Approximately 60 per cent were positive and 40 per cent negative for the first loop. Within the time range of the oscillograms obtained, two-thirds of the waves were oscillatory and one-third unidirectional.

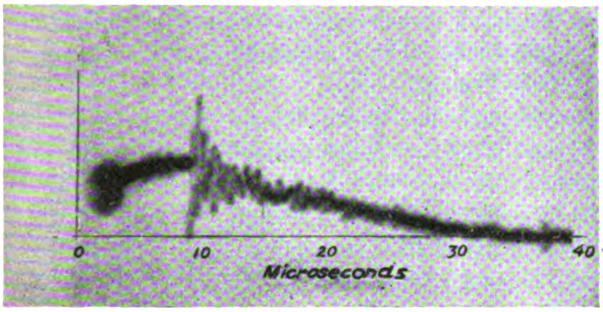

Fig. 5(A). First cathode-ray oscillogram of lightning surge on a transmission line. Taken at Wallenpaupack, July 27, 1928, on phase Y. The superimposed oscillations are due to flashover on an adjacent phase.

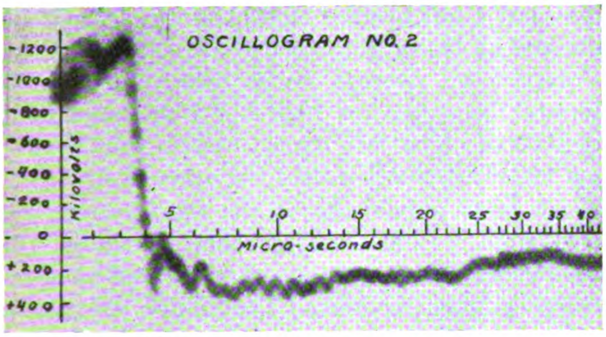

Fig. 5(B). Cathode-ray oscillogram (CD901180) obtained on May 29, 1929. Dead-end protective gaps at this point flashed over on all three phases. This flashover caused a sharp change in voltage from 1260 kv. negative to 310 kv. positive in one microsecond. Flashover took place on front of wave.

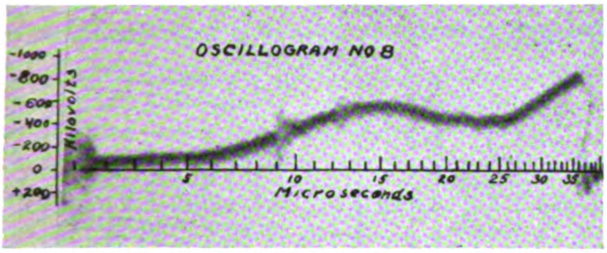

Fig. 5(C). Cathode-ray oscillogram (CD901194) taken on June 19, 1929. Record obtained while line was not energized. Voltage was still rising at the end of 36 microseconds and was then suddenly reduced to zero. Subsequent examination of line insulation indicated a flashover 23 miles away, which appeared to correlate with this oscillogram.

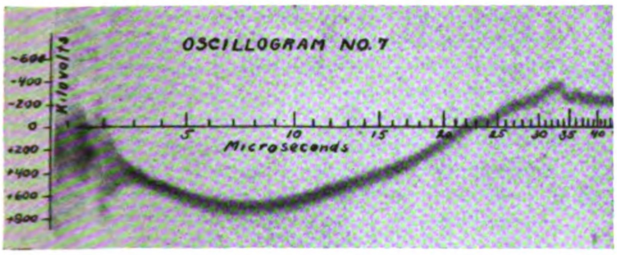

Fig. 5(D). Cathode-ray oscillogram (CD901193) taken on June 19, 1929. This is a wave which has a slightly oscillatory nature and is typical of a large group of waves. A cloud-to-ground stroke was seen at the instant this oscillogram was obtained. This stroke was at least 10 miles distant from the laboratory and some distance from the line.

Fig. 5. Cathode-ray Oscillograms Obtained at Wallenpaupack (Pa.)

In considering the magnitudes of these waves, and their front and duration, it should be remembered that all of the waves were measured at the terminal of the transmission line, and the voltage values recorded were influenced by reflection. In most cases the waves originated on the line many miles from the terminal. The waves, therefore, have been subjected to considerable attenuation in magnitude and change in form. Taking this into account and the extremely high magnitudes measured on the line by surge voltage recorders, it is reasonable to assume that many of the waves at their origin have fronts steeper than those measured by the cathode-ray oscillograph.

In Fig. 5 are shown the oscillogram of the 1928 surge, and oscillograms of three interesting surges obtained during 1929.

A cathode-ray oscillograph was installed in 1929 on the Ohio Power Company system at Newcomerstown. Ten lightning surges were recorded, of which only three were equal to or greater than normal (108 kv.). All the recorded surges were positive and all unidirectional. The wavefronts varied from four to 30 microseconds and the total duration from 45 to 60 microseconds.

In the Consumers' Power Co. investigation for 1928(8) seven cathode-ray oscillograms of lightning surges 200 kv. and above were obtained. The wavefronts varied from 0.5 to 7 microseconds. The total duration of the first loop varied from 0.7 to 40 microseconds. Four of the surges were of negative polarity and three positive. Five of the waves were unidirectional and two oscillatory.

(4). Attenuation

In 1927 plots were made of two surges which appeared at more than one station on the Pennsylvania Power and Light Co. system and six surges on the New England Power Co. system, with distance from an assumed origin as abscissas and voltage as ordinates.(9) An average curve was drawn and equations determined for the variations of voltage with distance and the rate of change of voltage with distance, or attenuation. These Equations are as follows:

$$e = \frac{e_o}{kse_o + 1} \qquad (1)$$

$$A = -ke^2 \qquad (2)$$

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(8) "Lightning Voltages on Transmission Lines," by R. H. George and J. R. Eaton, part of symposium at the Winter Convention on the subject of Lightning Investigation.

(9) "Surge Voltage Investigation on Transmission Lines," by W. W. Lewis, *Trans. A.I.E.E.*, Vol. 47, No. 4, 1928.

in which

e_0 = initial surge voltage at the point where the surge originated.
k = a proportionality factor which is found empirically.
s = distance in miles from the origin of the surge.
e = voltage at any distance s.
A = the attenuation in kilovolts per mile.

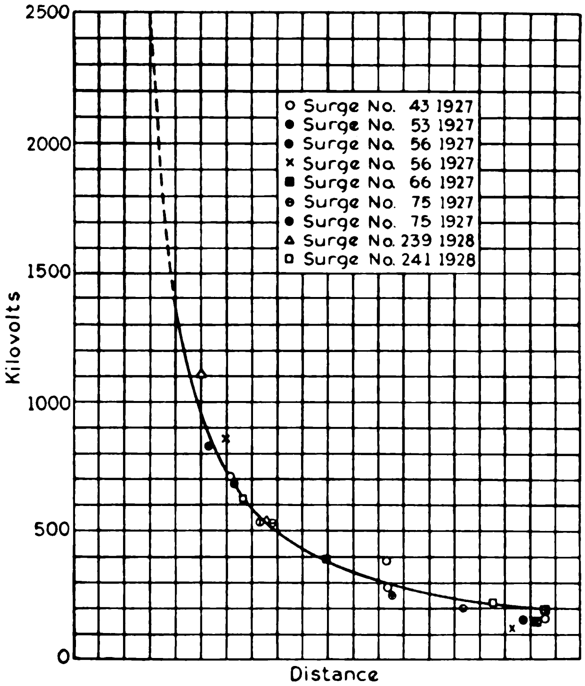

Fig. 6. Curve Showing Variation of Voltage with Distance for Various Surges Occurring on the New England Power Co. System in 1927 and 1928. Factor *k* from curve = 0.00016

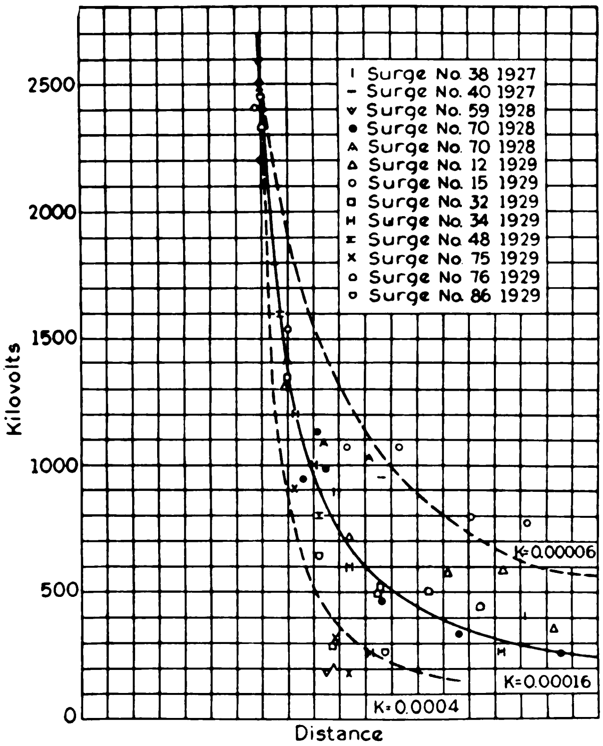

Fig. 7. Curve Showing Variation of Voltage with Distance for Various Surges Occurring on the Pennsylvania Power and Light Co. System in 1927, 1928, and 1929

The factor k for the surges investigated was found to be 0.00016.

The curve referred to has been replotted with the two surges from the Pennsylvania system omitted, thus confining the data to the six surges found on the New England Power system in 1927, together with two additional surges obtained on this system in 1928 (see Fig. 6).

Surges on the Pennsylvania system for 1927, 1928, and 1929 have been plotted in Fig. 7 and surges obtained on the Ohio Power system for 1928 and 1929 have been plotted in Fig. 8.

These data all tend to confirm the validity of Equations (1) and (2) derived in 1927.(9) There is, however, considerable difference in the factor k for the various systems. This factor from the New England surges is 0.00016. On the Pennsylvania system there is a considerable range in the points of the various surges, but a fair average curve through these points again gives a factor k of 0.00016. On the Ohio Power Co. system an average curve drawn through the points of the surges for 1928 and 1929 has a factor k of 0.00057. The last named system thus shows a much faster attenuation than the other two.

A few tests were made on the Ohio System with surges from a 1000-kv. lightning generator. The potentials at various points were measured by means of surge voltage recorders. The results are plotted on Fig. 9, the full curve representing an average of the various test points. The dotted curve is taken from Fig. 8, and represents the average attenuation measured with natural lightning surges.

Unfortunately, the surges placed on the transmission line from the lightning generator were not

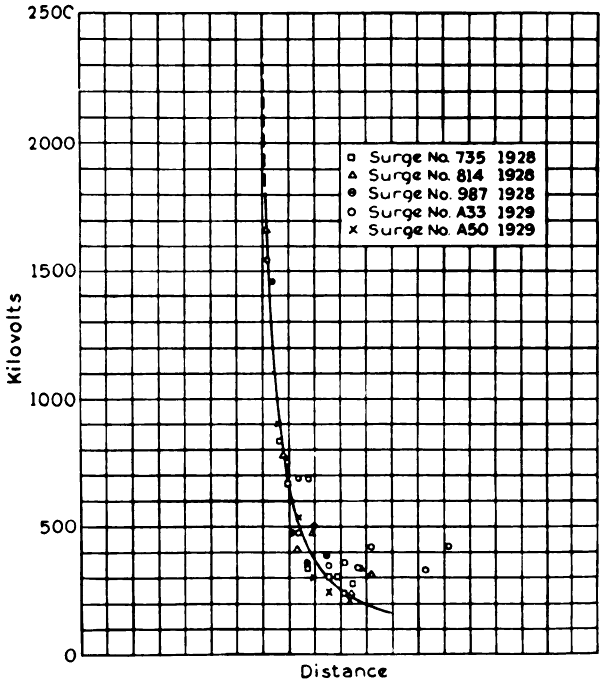

Fig. 8. Curve Showing Variation of Voltage with Distance for Various Surges Occurring on the Ohio Power Co. System in 1928 and 1929. Factor *k* from curve = 0.00057

of sufficient amplitude to permit the checking of attenuation over the voltage range of most interest in connection with natural lighting surges. However, in the limited range of these tests, the attenuation of the artificial surges appears to be of the same order as that of the natural surges.

In his work in Michigan(8) Mr. McEachron found factors k of the order of 0.00039 to 0.00049 when an artificial surge was placed on three conductors in multiple. With natural surges it is probable that three conductors in multiple are also involved, so that attenuation factors should be compared on this basis. Mr. McEachron also found it necessary to introduce an exponent to modify the distance s in the denominator of Equation (1). This exponent, however, does not differ greatly from unity, and for practical purposes it can probably be neglected.

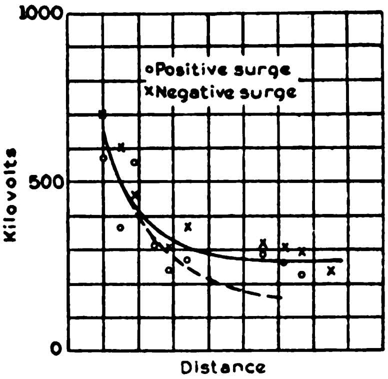

Fig. 9. Curve Showing Variation of Voltage with Distance for Artificial Surges Produced by Lightning Generator, Ohio Power Co. System, 1929. Dotted curve is from Fig. 8

It was found in the Michigan tests that k varied with the steepness of wave front, was different for positive and negative surges, and was different for a line with overhead ground wires and for a line without overhead ground wires.

A factor k of 0.00069 was found on the Turners Falls 66-kv. line when artificial surges were placed on a single conductor. (3)

While the attenuation factors from the various systems indicate that the wave attenuates faster with smaller conductors, it appears that other line and wave characteristics, such as those mentioned in connection with the Michigan tests, have considerable influence in affecting this factor k.

(5). Effect of Overhead Ground Wires in Reducing Surge Voltages

Ohio Power Company System

In 1927 approximately 50 surges were measured simultaneously on the top, middle, and bottom conductors of the vertically arranged circuits; in 1928 five surges were recorded; and in 1929 one surge. This line is a double-circuit line with one overhead ground wire above and midway between the two circuits.

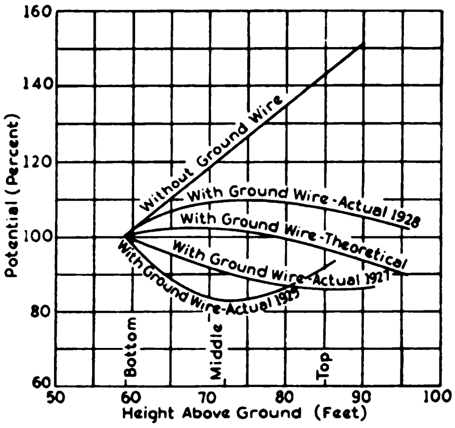

Fig. 10. Curves Illustrating Ground Wire Protection, Ohio Power Co. System, 1927, 1928, and 1929

In Table VII is given the theoretical potential of the three conductors without ground wire, expressed in per cent, on the assumption that the bottom conductor is 100 per cent and that the other conductors have potentials proportionate to their heights above ground. Then there is given the theoretical potential with ground wire, still assuming that the bottom conductor is 100 per cent and using the protective ratios 0.42, 0.52, and 0.62 for the top, middle, and bottom conductors, respectively.(10) Finally, the average of the surge voltage recorder readings are given, expressed in percent, with the bottom conductor taken as 100 per cent.

TABLE VII

EFFECT OF OVERHEAD GROUND WIRE

OHIO POWER COMPANY

Conductor	Approximate Height at Tower (Feet)	Theoretical Potential Without Ground Wire (Per Cent)	Theoretical Potential with Ground Wire * (Per Cent)	MEASURED POTENTIAL WITH GROUND WIRE AVERAGE OF READINGS (PER CENT)			
				1927	1928	1929	Weighted Average
Top	85	143	97	83-89**	99-116**	92	88
Middle	72	121	102	91	110	83	93
Bottom	59	100	100	100	100	100	100

* Calculated by means of tables in Footnote reference (10).
** First figure is comparison of top to middle, and second figure comparison top to bottom conductor.
1927 figures average of 51 to 54 surges. 1928 figures average of five surges. 1929 figures are one surge only.

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(10) "Relation Between Transmission Line Insulation and Transformer Insulation," by W. W. Lewis, *Trans. A.I.E.E.*, Vol. 47, No. 4, 1928, p. 992.

In the case of the top conductor two figures are given under the column of measured potential, the first is a comparison of the surges on the top and middle conductors and the second of the surges on the top and bottom conductors. The results are illustrated graphically in Fig. 10.

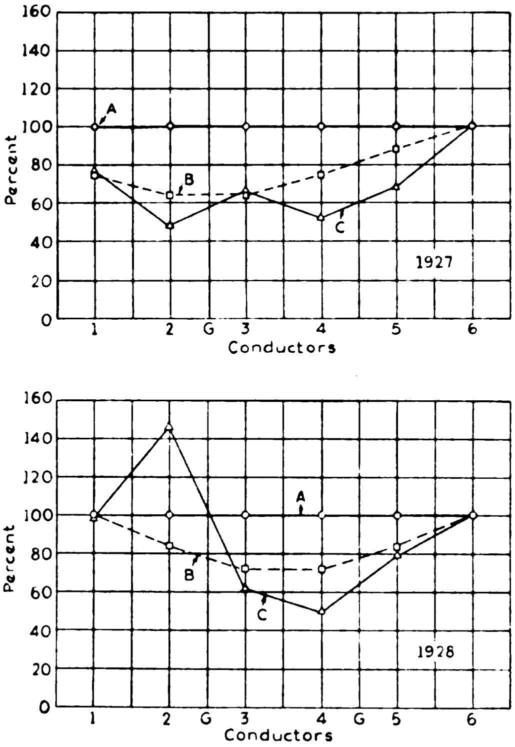

Fig. 11. Curves Illustrating Ground Wire Protection, New England Power Co. System, 1927 and 1928

(*A*). Without ground wires.
(*B*). With ground wires (estimated).
(*C*). With ground wires (measured by surge voltage recorder).

The last column of Table VII gives the weighted average for the three years. On account of the large number of surges recorded in 1927 compared with the two later years, the weighted average figures give a curve practically the same as the 1927 curve.

New England Power Company's System

This transmission line consists of two circuits arranged horizontally. The conductors may be designated 1, 2, 3, 4, 5, 6. In 1927 there was one ground wire above and between conductors 2 and 3. Instruments were installed on all six conductors at two places, Griswoldville and Barre. The readings on these instruments did not necessarily indicate the potential due to the conductor position at that point, because the conductors were frequently transposed. The fairest attempt to evaluate the effect of the ground wire was to select those surges which had their highest values at one of the stations, and therefore, presumably originated near that station. For this purpose five surges which had their highest values at Barre were studied. The average values of the surges expressed in times normal are given in Table VIII.

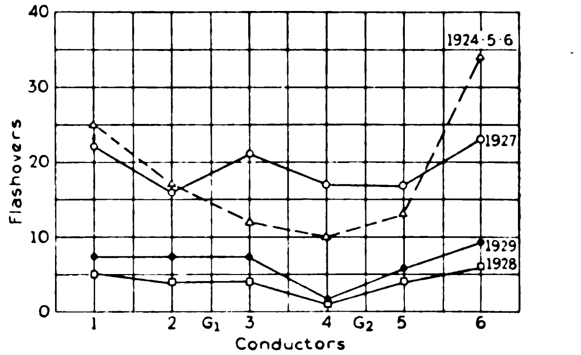

Fig. 12. Curves Showing Insulator String Flashover on New England Power Co. System, 1924 to 1929. Ground wire G_2 was installed in 1928.

In 1928 a second ground wire was placed above and between conductors 4 and 5. The average values of two surges having their highest values at Barre are given in Table VIII.

Fig. 11 illustrates graphically the effect of overhead ground wires for the years 1927 and 1928.

TABLE VIII

EFFECT OF OVERHEAD GROUND WIRE

NEW ENGLAND POWER COMPANY

Surge Voltages Having Their Highest Voltage at Barre

	1927						1928					
CONDUCTOR POSITION	1	2	G 3	4	5	6	1	2	G 3	4	G 5	6
Average of surge voltages (number of times normal)	4.8	3.1	4.2	3.3	4.4	6.4	4.2	6.4	2.7	2.1	3.4	4.3
Surge voltages in per cent (assuming Conductor 6 as 100 per cent)	75	49	66	52	69	100	98	146	63	49	79	100
Theoretical protective ratio* in per cent	74	64	64	74	89	100	100	84	72	72	84	100
Insulator flashovers	22	16	21	17	17	23	5	4	4	1	4	6
Lightning storms	22						20					
Insulator flashovers	116						24					
Tripouts	43						5					

*From Footnote Reference (10). G = Ground wire.

The number of insulator flashovers, storms and tripouts for 1927 and 1928 are also given in Table VIII.

In 1929 there were 13 tripouts on this line, and a total of 38 flashovers, divided among conductors 1 to 6 respectively as follows: 7, 7, 7, 2, 6, 9.

In Fig. 12 are shown the number of insulator string flashovers for each conductor, for the years 1924 to 1929.

In this connection it must be remembered that in addition to adding the second ground wire in 1928, the line insulation was also considerably improved, being increased from eight disks on all conductors to 10, 9, 8, 8, 9, 10 disks. Grading rings were also added at both line and ground ends of all strings.

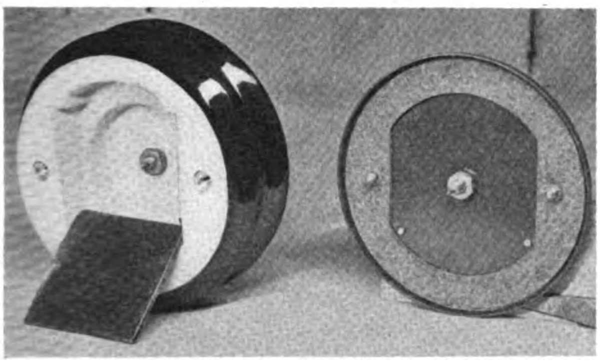

Fig. 13. Lightning Stroke Recorder

General

A similar improvement was shown on the Ohio Power Co. system previously described. In 1925 there were 88 tripouts. In 1926 a ground wire was added and grading rings at the line ends of all strings. The tripouts, as shown by Table IV, have not exceeded 15 per year since that time. There is no doubt that the ground wire should be credited with some of this improvement in operation.

Some data were secured on antennas at Wallenpaupack during a lightning stroke. An antenna 50 ft. from the ground with a grounded conductor 10 ft. above, registered a potential approximately one-half that recorded on a similar 50-ft. antenna without ground wire.

The Overhead Systems Committee of the Great Lakes Division, National Electric Light Association,(11) made a study of the operation of high voltage transmission lines during 1927. The lines without overhead ground wires (728 miles) had 12.2 interruptions per 100 miles due to lightning, while the lines with overhead ground wires (1511 miles) had 5.9 interruptions per 100 miles due to lighting.

A similar study was made for 1928 operation.(11) The lines without overhead ground wires (719 miles) had 16.8 interruptions per 100 miles, and the lines with overhead ground wires (1576 miles) had 8.1 interruptions per 100 miles. The data for the two years indicate approximately twice as many interruptions per 100 miles on lines without ground wires as on lines with ground wires.

The Texas Power and Light Company in 1925 operated 726 miles of 60-kv. line with overhead ground wire. On these lines there were 28 interruptions or approximately four interruptions per 100 miles. During the same year this company operated 491 miles of 66-kv. line without overhead ground wire. The interruptions were 75, or about 15 per 100 miles. In 1926 they had 800 miles with ground wire, and the interruptions were 64, or eight per 100 miles. In the same year they had 784 miles without ground wire. The interruptions were 220, or 28 per 100 miles.

All these data, though incomplete, give corroborative evidence of the value of the overhead ground wire in improving the continuity of service.

(6). **Lightning Stroke Recorders**

In 1929 lightning stroke recorders were placed in service on 284 of the approximately 300 towers of the Wallenpaupack-Siegfried line, and on about 20 towers of the Philo-Canton line.

Fig. 13 is a view of the recorder. This recorder is a small Lichtenberg camera, which is placed across a portion of a leg of a transmission tower. The development of the instrument and its application are due to Mr. W. L. Lloyd of the Pittsfield High Voltage Laboratory, and the results were interpreted by Mr. Lloyd. For a complete description of this instrument, see the companion paper by Sporn and Lloyd.(4)

The film for this instrument consists of two sheets separated by tinfoil and wrapped in treated paper, the whole forming a lightproof and waterproof packet, so that the instrument can be readily loaded in the field. The film is inserted in the camera and pressure is applied till the film is held firmly in place, with the electrodes against the outside wrapping of the packet.

The theory of the device is that a direct stroke hitting the tower or flashing over an insulator will cause sufficient current to flow down the tower leg to give an appreciable drop, and consequently a Lichtenberg figure on the film. The current flowing when an insulator flashover due to an induced stroke will not be sufficient to cause enough drop in the tower leg to give a figure on the film.

Four figures were obtained, two on the Wallenpaupack-Siegfried line and two on the Philo-Canton line.

The first Pennsylvania record was obtained on August 27th at Tower 26–2 (Siegfried-Roseland Section). This record was interpreted to indicate about 60,000-amp., negative polarity. At the same time the surge voltage recorder at this tower indicated a positive surge of 2400-2800 kv. (13.3 to 15.5 times normal).

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(11) "Report of Overhead Systems Committee, Great Lakes Division, National Electric Light Association," Sept., 1928. Also report of same committee October, 1929.

An oscillogram of low voltage amplitude was taken of this surge at the lightning laboratory (about 40 miles from the origin of the surge). Tripout 33 was associated with this surge.

The second Pennsylvania record was obtained September 10th at Tower 12–5 (Wallenpaupack Tap section). This tower is at High Knob, in the section of line equipped with a counterpoise.(4) The record was interpreted to indicate about 100,000-amp., negative polarity. There was no surge voltage recorder at this tower and the recorder at the next (Tower 12-6) was out of service. The recorder at Tower 10–2 (the nearest recorder north) indicated a positive surge of 350 kv., which it is thought correlates with the surge indicated by the lightning stroke recorder. The surge voltage recorder at Tower 17–9 (the nearest recorder south) gave no indication. No tripout accompanied this surge.

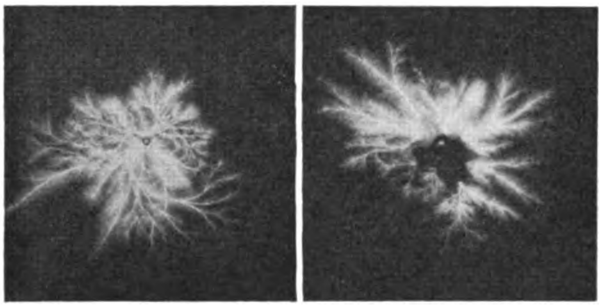


Fig. 14. Figure Obtained with Lightning Stroke Recorder on Ohio Power Co. System, July 25, 1929, Surge A-50

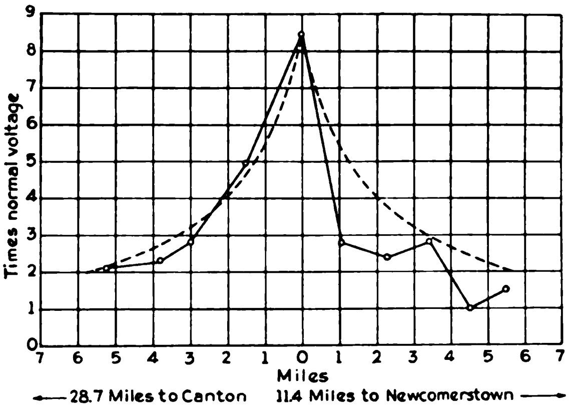


Fig. 15. Attenuation of Surge A-50, Which Occurred on Ohio Power Co. System July 25, 1929. (See Fig. 14 for lightning stroke recorder registration.) Dotted curve shows attenuation calculated from Equation (1), with $K = 0.0006$

The first Ohio record was obtained on July 25th at 3:20 p.m. on Tower 185 and indicated approximately 175,000-amp. negative polarity (see Fig. 14). At the same time, the surge voltage recorder on the transmission conductor on this tower indicated a positive surge of 8.4 times normal (Surge A-50). There was no tripout. A good attenuation curve was obtained of this surge by means of surge voltage recorders (see Fig. 15).

The second Ohio record was thought to have been obtained on August 23 at 2:58 a.m. This was at Tower 159. The recorder indicated a surge of approximately 100,000 amp., negative polarity. At the same time, the line surge voltage recorder indicated a positive surge of 6.5 times normal at this tower (Surge A-72). This surge was accompanied by a tripout.

There is a large field for an instrument of this sort, but the records obtained so far are too few to draw any conclusions as to the value of the instrument for the purpose intended. It is planned to continue the operation of these instruments for another year.

(7). Field Intensity Recorder and Rate of Change of Field Intensity Recorder

Two instruments were built and placed in operation at the Wallenpaupack laboratory, in an effort to obtain some measurements with regard to electric field conditions to which transmission conductors might be subjected. These instruments are called respectively "a field intensity recorder" and "a rate of change of field intensity recorder."

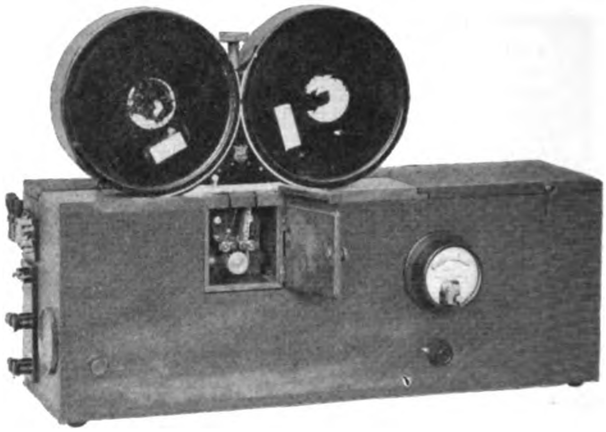


Fig. 16. Field Intensity Recorder

The instruments were developed and applied under the supervision of Mr. H. B. Marvin of the General Engineering Laboratory, Schenectady, and the data obtained were analyzed by Mr. Marvin.

The purpose of the field intensity recorder is to obtain a photographic record on a motion picture film of the vertical component of electric field intensity (voltage gradient) versus time. The purpose of the rate of change recorder is to obtain a photographic record of the vertical component of the time rate of change of electric field intensity. The adjustment is made so that only relatively large values, such as occur during thunderstorms are recorded. The data so obtained are expected to be helpful in two ways: (a) to acquire further knowledge of the nature of lightning strokes; (b) in measuring the relative severity of thunderstorms.

Instruments were installed in a small building near the lightning laboratory at Wallenpaupack and operation began on May 28, 1929, and continued throughout the lightning season. During that time the recorders went through more than 33 storm periods. Each recorder used approximately 1400 ft. of motion picture film. The field intensity recorder operated satisfactorily from the first, but the rate of change recorder produced blank records until after August 5th, at which time changes were made in the instrument to increase its sensitivity and it was adjusted for slower rates of change. Following these changes records were obtained on this instrument also.

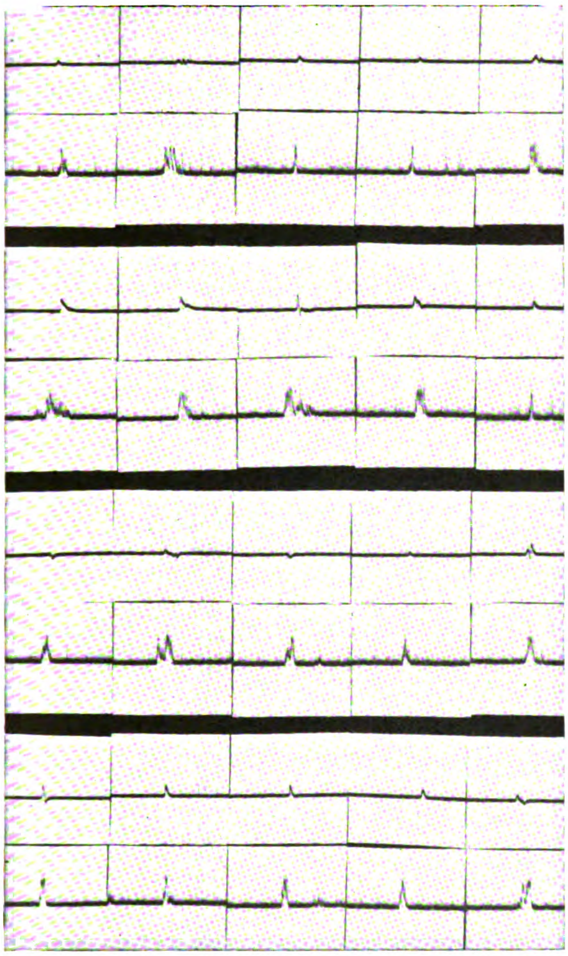


Fig. 17. Typical Record Obtained with Field Intensity Recorder (Upper) and with Rate of Change of Field Recorder (Lower)

Fig. 16 shows a view of the field intensity recorder and Fig. 17 shows a typical record taken with this instrument, also a record obtained at the same time with the rate of change of field recorder.

Records obtained from the field intensity recorder were measured, and the data plotted for each storm on cross-section paper, the abscissas representing time and the ordinates kilovolts per meter. Fig. 18 shows the data for the storm of June 19, 1929.

A study of the records indicates that the readings for any one storm are usually of one predominant polarity, which may be either positive or negative. Of 33 storm periods studied, about 40 per cent gave readings predominantly positive, about 40 per cent predominantly negative and about 20 per cent mixed positive and negative.

In Fig. 19, kilovolts per meter are plotted as abscissa against the number of strokes as ordinates, as measured by the field intensity recorder.

In Fig. 20 an attempt is made to correlate the potential gradient with distance of the stroke from the laboratory. The distance was determined roughly by an observer in the cupola of the laboratory, with the assistance of a stop watch and a device for sighting on the stroke. Of 253 strokes over 15 kv.

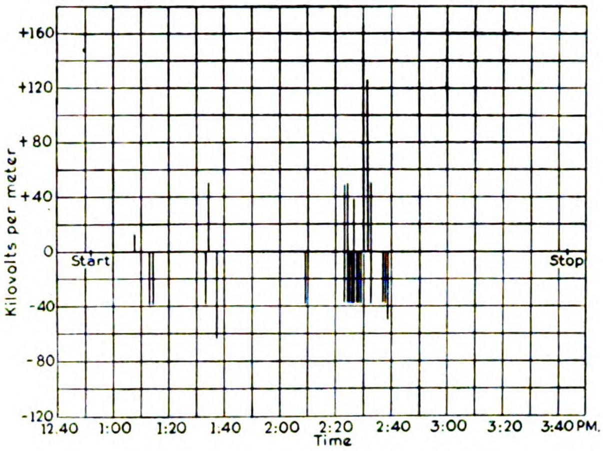


Fig. 18. Field Intensity Data Obtained by the Field Intensity Recorder During the Storm of June 19, 1929

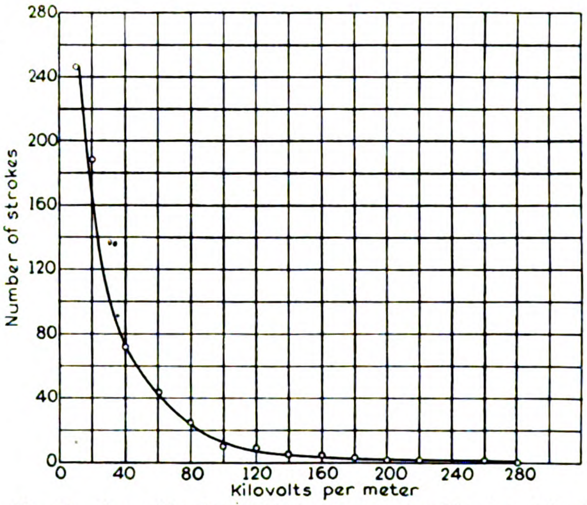


Fig. 19. Curve Showing Field Gradient Against Number of Strokes as Obtained by the Field Intensity Recorder During the 1929 Season. Ordinates represent number of strokes giving intensity greater than specified value

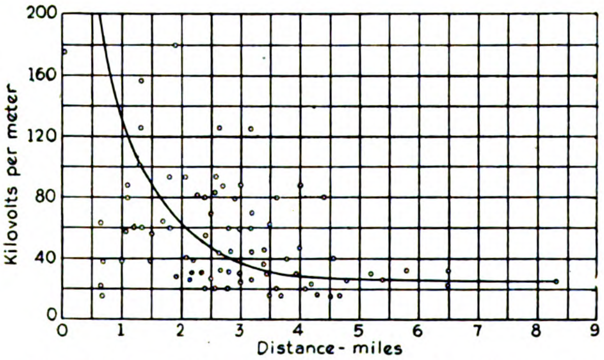


Fig. 20. Correlation of Potential Gradient with Distance of Stroke from Wallenpaupack Laboratory, Season of 1929

per meter recorded, it was possible to correlate in this manner only 81 strokes, or 32 per cent of those occurring. The other strokes were too uncertain in correlation or else no satisfactory distance measurement was obtained. It will be noticed that the correlation is very rough but that there is a tendency for a curve showing greater field intensity with shorter distance from the laboratory.

Up to the time of writing this article it has not been possible to determine the meaning of the records obtained from the rate of change of field intensity recorder, and their discussion will be left until a later date.

(8). Conclusions

A vast amount of progress has been made in the study of the effects of lightning on transmission lines in the past two years.

The upper limits of 15.2 times normal voltage for lightning surges and 5.5 times normal for switching surges have been reached.

Gradients as high as 52 kv. per ft. of height have been recorded on transmission lines, and 85 kv. per ft. on special antennas.

Tripouts have occurred on the lines under investigation as high as 29 per 100 miles per year, with 3.6 flashed insulator assemblies per tripout.

About 115 cathode-ray oscillograms of natural lightning were obtained on the Pennsylvania, Ohio, and Consumers' Power systems, ranging from low values to 1260 kv. Wave fronts varied from less than one to approximately 80 microseconds and the total duration of first loop from less than one to over 150 microseconds. Unidirectional waves and positive polarity predominated.

The formulas developed from the 1927 results for attenuation(9) have been substantiated, both by results from natural lightning and from artificial lightning. The factor *k* for natural lightning has been found to average 0.00016 on the New England and Pennsylvania systems. For Ohio the factor is 0.00057. Artificial lightning surges on the Michigan system gave a factor of the order of 0.00044 and on the Turners Falls system of the order of 0.00069.

Attenuation apparently varies with the size of conductor, with the steepness of wavefront, with the polarity of the wave, with the presence or absence of ground wires, and possibly other factors.

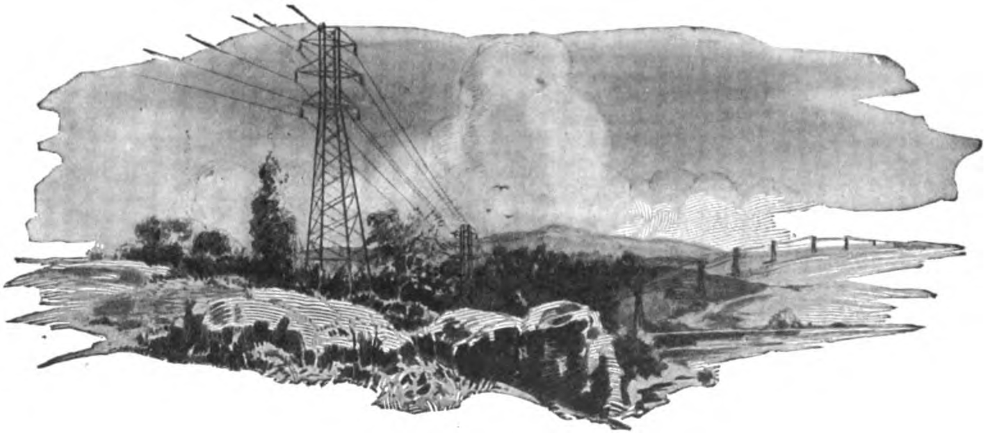
The value of overhead ground wires in reducing induced potential and in reducing tripouts has been demonstrated by test and by operating experience.

Lightning stroke recorders have been introduced and a few records obtained. These give promise of much usefulness in the future.

Field intensity recorders and rate of change of field intensity recorders have been used and considerable valuable data obtained. Gradients as high as 85 kv. per ft. have been recorded. These instruments promise to yield a good deal of information about the habits of storms.

The intensive observation of storm conditions at the Pennsylvania Lightning Laboratory indicated that in 1929 there were 24 cloud-to-ground strokes within a one-mile radius in this vicinity.

In a future work an attempt will be made to differentiate between the surges and flashovers due to induced strokes and direct strokes. An attempt will be made to record by the cathode-ray oscillograph the wave-shapes of some of the extremely high voltages which have been found by surge voltage recorder. The effects of counterpoises or grounded conductors under the transmission line will be studied. Attenuation will be further studied both with natural and artificial lightning. Devices to prevent flashover (line type arresters) will probably be tried out by tests during the coming year.



The Application of Oxygen and Hydrogen to Industrial Operations

PART VII

THE ECONOMICS OF HYDROGEN PROCUREMENT

By **F. P. WILSON, Jr.**
Schenectady Works Laboratory, General Electric Company

INDUSTRY is slowly beginning to recognize the tremendous opportunities for economy which lie in the application of industrial gases. New uses are being developed and the older applications are being more generally utilized.

The next decade will undoubtedly witness an unprecedented increase in potential demands for various gases among which hydrogen may be listed. The growth in the uses of hydrogen in the past has been retarded by a combination of circumstances, the most important of which have been its high cost, its deficient availability feature, and a lack of general knowledge regarding procurement economics. In addition, its industrial possibilities have not until recently been recognized to the extent which is warranted by its value as a tool. Indicated savings and improvements made possible in the mechanical industries through the proper use of hydrogen emphasize the importance of procurement at a price which will permit its economical use.

The manufacture, distribution, and use of gases, particularly hydrogen, is closely related to the electrical industry. Electrical equipment is involved either in its production, distribution, or application.

The tremendous advantages derived in the oil refinery business through the use of hydrogen can also be duplicated in the mechanical industries when the processes of application and economic procurement are fully understood. In the last analysis, the cost of hydrogen is the controlling factor in the operating costs of copper brazing, atomic-hydrogen welding, cutting, bright annealing, and similar activities when carried out on a large scale. The high cost of commercial hydrogen limits the number of applications involving its use. With such facts duly recognized, the next step is in the direction of economical hydrogen procurement.

There are numerous methods of hydrogen production and the economic selection of any one process of manufacture must be based on a thorough study of the prevailing conditions. No one method can be assumed preferable until the following factors have been carefully analyzed:

(1). What are the immediate and potential uses for hydrogen?
(2). What is the particular function of hydrogen in these applications?
(3). Based on such information, what are the purity limitations?
(4). What methods of hydrogen production conform to such limitations?
(5). Which method is preferred among this group, having in mind:
    (*a*). Investment cost.
    (*b*). Operating cost.
    (*c*). Maintenance.
    (*d*). Obsolescence.
    (*e*). Safety.
    (*f*). Possible use for by-products.
    (*g*). Relation of process to other gas activities.
    (*h*). Nature and size of hydrogen load.
    (*i*). Miscellaneous factors.
(6). What differential exists between the cost of hydrogen produced by the process selected and the cost of hydrogen available from the commercial sources of supply?

Purity Limitations

When considering hydrogen manufacturing processes, it is essential that purity limitations and their relation to hydrogen manufacturing economics be defined. The majority of the industrial uses for hydrogen in the mechanical industries do not require 99 per cent purity. Such refinement is necessary in many chemical activities and laboratory investigations, but for the work under consideration, such purity is not essential. *Freedom from oxygen is of course necessary*, but such gases as nitrogen, carbon monoxide, methane, and carbon dioxide can be present in definite amounts with no detrimental effect in the following applications:

(1). Copper brazing of steel parts.
(2). Bright annealing.
(3). Carburizing.

The following table facilitates the location of material hitherto published in this serial :

Part	*Issue*	*Figs.*	*Tables*
Part I	Nov. 1927, p. 544	1 to 9	I to V
Part II	Dec. 1927, p. 590	10 to 16	VI
Part III	Apr. 1928, p. 197	17 to 25	VII to IX
Part IV	May 1928, p. 279	26	X
Part V	July 1928, p. 385	27 to 29	—
Part VI	Sept. 1928, p. 493	30	XI

(4). As a fuel gas in an oxy-gas metal-cutting torch.
(5). Atomic-hydrogen welding.
(6). Flame operation, such as lead burning, glass blowing, etc.

There are limits for the amount of such constituents, but the general impression that industrial hydrogen is limited to a gas of 99 per cent purity is incorrect. In any of the named applications, 75 per cent hydrogen (and sometimes less) is satisfactory, provided the percentage of the various gaseous impurities does not exceed the maximum allowable for the application involved. For example, hydrogen and carbon monoxide mixtures may contain more of the latter gas if such a mixture is to be used for metal cutting or copper brazing than would be allowable for use in an atomic-hydrogen welding torch.

Copper Brazing of Steel Parts

The function of the gas atmosphere in an electric brazing furnace has been described in preceding issues of this magazine.(6) (7) For this reason consideration will here be given only to the range of impurities permissible in hydrogen for this application and the relation which such a range bears to the choice of a hydrogen manufacturing process.

Briefly, the furnace atmosphere must first be capable of reducing the oxides of the various metals used in such brazing operations. There may also be instances where atmospheres are desirable which have one of the following characteristics:

(1). Carburizing
(2). Neutral to carbon

Almost any gas capable of being easily oxidized satisfies the first condition. The second condition, involving carbon, hydrogen, methane equilibrium, is not so easily satisfied. In either case, however, the various gaseous mixtures permissible or desirable with hydrogen are indications as to what method of hydrogen manufacture may be preferable.

Mixtures of hydrogen and nitrogen may be used in a brazing or annealing furnace, but as the nitrogen concentration increases, the reducing power of the mixture decreases and the need for dry conditions in the furnace is increased if satisfactory work is to result.

Carbon dioxide and steam, if present in quantities which exceed equilibrium conditions, are oxidizing and therefore undesirable.

Carbon monoxide, because of the equilibrium relation between CO, CO_2, and iron oxide, is the ideal gas for brazing furnaces. Therefore hydrogen containing carbon monoxide will give superior results in brazing. The effect of carbon monoxide on the electric heating units will not produce nickel carbonyl at temperatures above 100 deg. C. and therefore is not objectionable from this viewpoint.

Methane as a rule should not be present in quantities exceeding equilibrium conditions at the operating temperature of the furnace, unless a carburizing atmosphere is desired. By control of the methane content of hydrogen delivered to the furnace, a carburizing atmosphere or an atmosphere neutral to carbon may be produced as desired.

Choice of Gas Atmosphere for Electric Furnaces

The choice of a gas atmosphere for brazing furnaces or electric annealing furnaces depends upon:

(1). The function which such an atmosphere is to perform.
(2). The nature of the work to be placed in the furnace.
(3). The furnace design.
(4). The operating cycle.
(5). The availability, quality, and cost of the gases.

The effects of various gaseous impurities in hydrogen in the application of this gas to copper brazing have been very briefly considered. The amounts of these impurities in hydrogen when produced by various methods are well known. There is thus a relation between purity limitations for hydrogen use and methods of production which should assist in the selection of a method of hydrogen procurement.

In Table XII are shown gaseous mixtures which have been successfully used in brazing furnaces for a great variety of work. The mixtures indicate the range of gaseous impurities with which it is possible to obtain satisfactory results, not for all conditions but in those applications where the indicated mixture satisfied requirements.

TABLE XII

GAS MIXTURES SUCCESSFULLY APPLIED IN BRAZING FURNACES

Mixture	PER CENT BY VOLUME			
	Hydrogen	Nitrogen	Carbon Monoxide	Methane
No. 1	15	85	. .	. .
No. 2	75	25	. .	. .
No. 3	71	2	21	6*
No. 4	30	. .	68	2*
No. 5	100	. .	. .	. .

*With these mixtures sufficient moisture was present in the furnace atmosphere to react with and remove the carbon produced by the dissociation of the methane.

These various factors are emphasized to give an idea of the variables involved. A detailed treatment would require prohibitive space, but consideration of these various features should give an impetus to this gas process which possesses great economic possibilities in the mechanical industries.

Bright Annealing

In this application, reducing or non-oxidizing and non-carburizing conditions are desirable. Hydrogen with nitrogen, carbon monoxide, or methane as impurities forms a satisfactory gas medium, provided of course such impurities conform in amount to the requirements of the particular application involved.

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(6) "The Application of Oxygen and Hydrogen to Industrial Operations: Part VI: Hydrogen, Nitrogen and the Electric Furnace," by F. P. Wilson, Jr., GENERAL ELECTRIC REVIEW, Sept., 1928, p. 493.

(7) "Industrial Electric Heating: Parts X and XI: Furnace Atmospheres," by N. R. Stansel and C. Dantsizen, GENERAL ELECTRIC REVIEW, May, 1929, p. 278, and August, 1929, p. 448.

Carburizing

A detailed treatment of carburizing, neutral, and decarburizing atmospheres in electric furnaces has already been published in this magazine,(7) and the subject is mentioned here only to indicate another use for hydrogen containing methane as an impurity. Satisfactory carburizing results can also be obtained with butane-hydrogen mixtures. A further analysis of gas carburizing will be made in a later installment of this serial.

Metal Cutting

This field offers great possibilities for fuel gases which can be obtained more cheaply than acetylene and which will perform almost as well. At many points the quality of the city gas supplied is such that it is admirably adapted to this purpose. In most cases, however, it contains constituents such as methane and illuminants in appreciable quantities. These result in low flame temperature, low rate of flame travel, and high oxygen to fuel gas ratio. Hydrogen produced by cracking city gas forms an ideal cutting fuel and in most cases this process is without a competitor for this application. The impurities which should be reduced to a minimum are nitrogen, methane, carbon dioxide, and illuminants. Hydrogen and carbon monoxide constitute the valuable components for metal cutting.

Atomic-hydrogen Welding

The purity of hydrogen is an important factor in this application. Hydrocarbon gases and carbon monoxide dissociate at temperatures encountered in the atomic arc. The liberated carbon combines with the tungsten electrodes of the torch, forming tungsten carbide which has a lower melting point. A high electrode consumption ensues. The theory of the atomic torch has been covered in preceding issues of this magazine(8) and no further consideration is needed here other than to indicate gas mixtures which have been successfully used for this type of welding. These are listed in Table XIII.

TABLE XIII
GAS MIXTURES SUCCESSFULLY USED IN ATOMIC-HYDROGEN TORCH

Mixture	PER CENT BY VOLUME			
	Hydrogen	Nitrogen	Carbon Monoxide	Methane
No. 1	75	25	..	..
No. 2	80	4	5	11
No. 3	75	6	15	4
No. 4	100	..	..	..

Choice of Process

Having briefly considered the relation of impurities in hydrogen to its various applications, it now remains to indicate the various methods of producing hydrogen and the economic factors affecting a choice of process.

There are several major combinations of circumstances which dictate whether hydrogen should be produced by:

(1). A by-product process.
(2). A process involving no by-products.

The selection of one of these general groups depends of course upon the possible use of by-products, and in the by-products group of processes the one of major interest is that based on the electrolysis of water. Oxygen is the by-product and has considerable utility as has been indicated previously in this magazine(9). If a need for oxygen exists, or if a market can be found, the problem is a choice between: (a) the electrolytic process which gives oxygen and hydrogen simultaneously or (b) the liquefaction process of oxygen manufacture and a method of hydrogen production involving no by-products. Either combination will give oxygen and hydrogen, and preference must be based on the study of a great variety of factors which will differ at each potential consumption point.

Knowing the purity of the gases produced by various processes, knowing in which general group the preferred process falls, and knowing the actual cost of hydrogen produced by the processes in this group, an intelligent selection should be facilitated.

METHODS OF HYDROGEN PRODUCTION

The following list does not include all the processes of hydrogen production, but it is believed that those of greatest industrial importance are indicated.

By-product Group

(1). Electrolysis of water.
(2). Iron contact process.
(3). Liquefaction of water gas.
(4). Steam and water gas, using catalysts.

Non By-product Group

(1). Dissociation of ammonia.
(2). Cracking of oil, natural gas, or other hydrocarbons.
(3). Cracking of city gas.

Electrolytic Process

The fact that an electric current will decompose water into oxygen and hydrogen was established at the beginning of the 19th century. The fundamental reaction, which is $2\ H_2O = 2\ H_2 + O_2$, is produced by passing direct current through a dilute solution of sodium hydroxide (NaOH) or potassium hydroxide (KOH).

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(8) "Flames of Atomic Hydrogen," by Irving Langmuir, GENERAL ELECTRIC REVIEW, March, 1926, p. 153.
"Atomic Hydrogen Arc Welding," by R. A. Weinman, GENERAL ELECTRIC REVIEW, March, 1926, p. 160.

(9) "The Application of Oxygen and Hydrogen to Industrial Operations: Part II: The Uses and Characteristics of Oxygen," by F. P. Wilson, Jr., GENERAL ELECTRIC REVIEW, Dec., 1927, p. 590.

The utilization of this process is favored if the following conditions prevail either singly or in combination:

(1). Pure hydrogen necessary.
(2). Uses for by-product oxygen.
(3). Cheap power rate.
(4). Gas loads large enough to justify the capital investment necessary.

The maintenance and labor costs are very low with the electrolytic process and the simplicity of its operation is an advantage. By this process, 60,000 cu. ft. of hydrogen per day can be manufactured and placed in the gas holder at $1.80 per thousand cubic feet, allowing a credit of one-third for the by-product oxygen.

Iron Contact Process

A large proportion of the hydrogen which is used for the hydrogenation of oils is produced by the interaction of steam with iron at temperatures ranging from 600 to 800 deg. C. The reaction is $3\ Fe + 4\ H_2O = Fe_3O_4 + 4\ H_2$. This reaction is reversible. In actual practice, water gas is used to reduce the iron oxide to metallic iron which is again treated with steam for the production of additional quantities of hydrogen.

For large quantities of gas produced by regular and constant operation, this method is possibly as cheap as any other method. It is not suitable, however, for producing relatively small volumes of gas or for intermittent operation. The method was used for many years for the production of hydrogen for airships, but owing to intermittent operation and heavy overhead, in this service, the hydrogen costs at times as much as $15 or $20 per thousand cubic feet. The labor, material, and maintenance costs are the greatest in this method. In a plant producing 60,000 cu. ft. of hydrogen per day (continuous 24-hr. operation) the cost of hydrogen in the gas holder will approximate $1.90 per thousand cubic feet.

The iron-contact process involves the installation of water-gas equipment in addition to the hydrogen-generating apparatus, and this results in a high total capital investment. The justification for plants of this type is therefore found only in large hydrogen loads.

Liquefaction Process

There are two principal liquefaction methods for the production of hydrogen; the first uses the nozzle-expansion principle and the second the expansion engine. In both cases water gas, from which carbon dioxide and hydrogen sulphide have been removed, is expanded after compression and pre-cooling. The water gas is liquefied as a result of the low temperature produced by the pressure drop. Fractional distillation of the liquid results in hydrogen containing less than 3 per cent of CO.

The economical procurement of hydrogen by this process is dependent upon appreciably large loads, such as prevail at plants producing ammonia. In a plant the same size as that mentioned, the comparative cost would be approximately $2.40 per thousand cubic feet.

Steam and Water Gas in Presence of Catalysts

By a continuous catalytic process, steam is blown through incandescent coke and the resulting water gas after being mixed with excess steam is passed into retorts which are maintained at red heat. Hydrogen and carbon dioxide are thus formed and the latter is removed by water under pressure, followed by alkali washing. A catalyst is necessary for the second reaction, nickel being the common one. This process is not used to any great extent in this country and for the average industrial needs one of the other processes is preferable.

Ammonia Dissociation

Liquid ammonia available in tanks can be gasified and dissociated at approximately 900 deg. C. in a properly designed retort. The cost of the resulting gas, which consists of 75 per cent hydrogen and 25 per cent nitrogen by volume, approximates $4 per thousand cubic ft. This process is simple, the investment charge is small and for many applications it is admirably suited.

Cracked Oil, Natural Gas, or Other Hydrocarbons

The following reactions are typical of what takes place when certain hydrocarbons are treated with steam:

$$CH_4 + H_2O = CO + 3\ H_2$$
$$CH_4 + 2\ H_2O = CO_2 + 4\ H_2$$

The reactions are reversible. The process is one of catalytic production in the presence of reduced nickel or other catalyst between temperatures of 200 and 400 deg. C. In a process which utilizes heavy oils or tars, the hydrocarbons are decomposed by means of generators filled with coke kept at high temperature. Hydrogen of 85 per cent purity is claimed for this process, most of the carbon being removed as carbon black. Still another method produces hydrogen by cracking natural gas.

(To be continued)

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GENERAL ELECTRIC REVIEW

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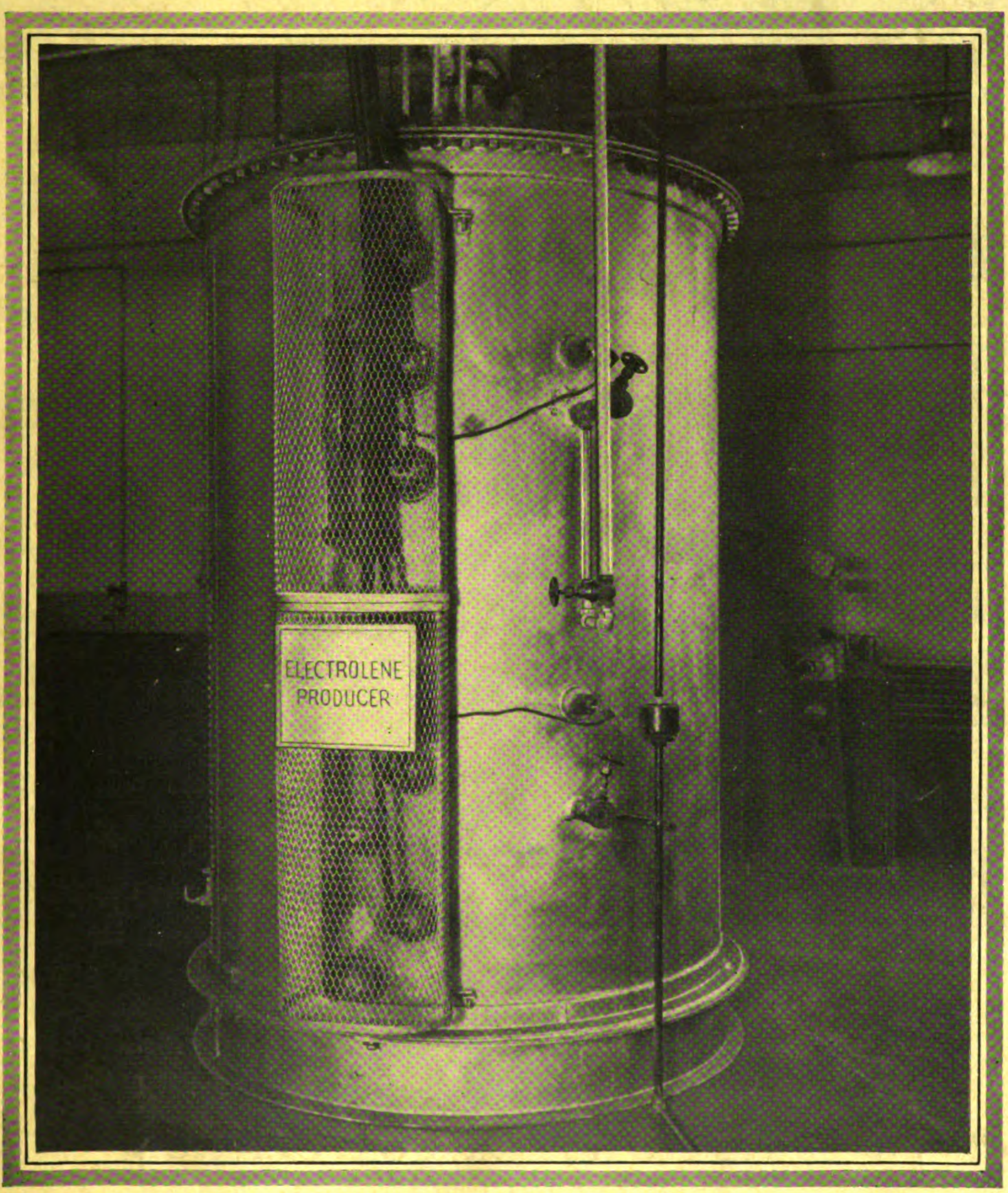
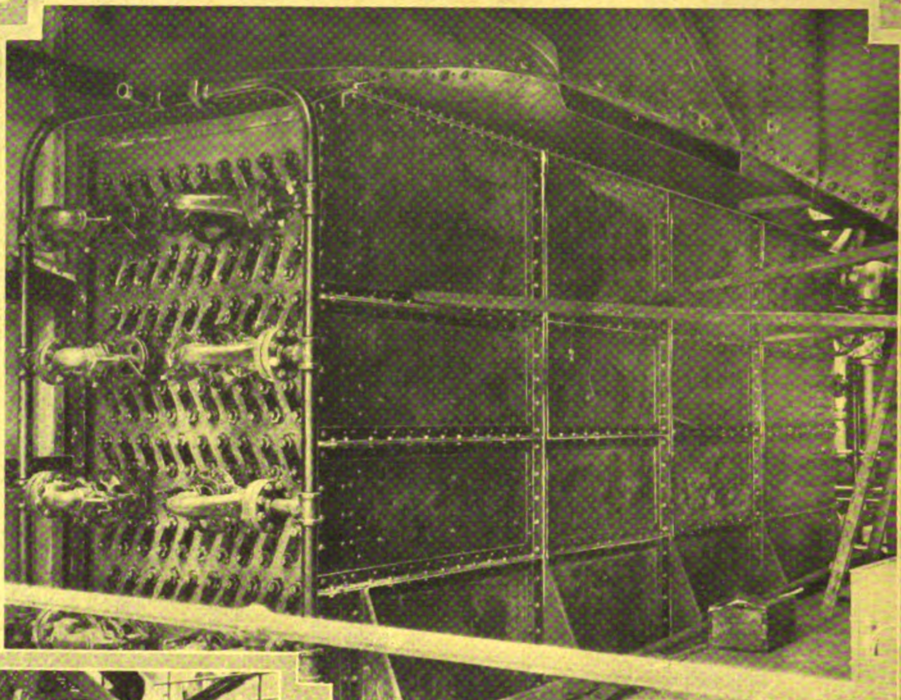


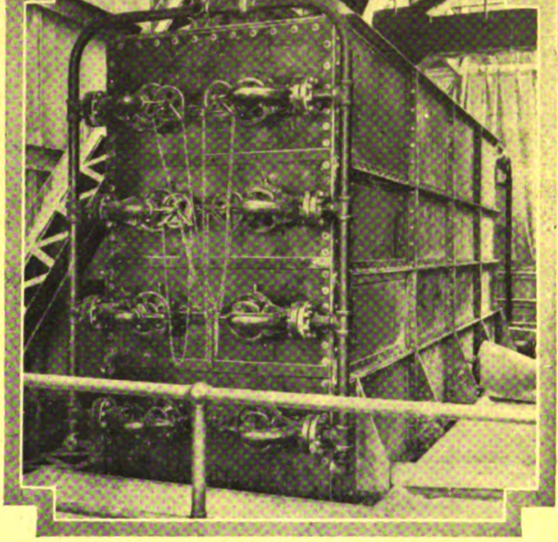
A NEW USE FOR ELECTRICITY

Electrolene is a low-cost gas formed by the partial or the complete dissociation of a hydrocarbon with or without steam. The output of this electrically-heated producer is suitable as the atmosphere for electric annealing, brazing, and heat-treating furnaces, and for metal cutting and certain other flame applications

(*See p. 222*)

In This Issue: *Dimensional Analysis* *Metal-clad Switchgear* *Modernization of a Railway* *Skin Effect in Tubular Conductors* *Electrolene* *Directed Planar Quantities* *Cable Heating in Underground Ducts* *Traveling Waves* *The Current Impulse Transformer*





Central Station Economizers

The illustrations show two of sixteen economizers used with eight twin Stirling boilers of 3069 hp. each. At 450 lb. pressure and high rates of driving, these Foster Wheeler economizers recover heat from the flue gases and raise the temperature of boiler feed water to 347 deg. F.

The higher the load, the more heat the economizers will recover. They thus maintain a high average efficiency over wide ranges of operation. The saving in fuel, the improved boiler operation, the reduced first cost for maximum load and the composite element construction have placed Foster Wheeler economizers far in advance of any yet produced.

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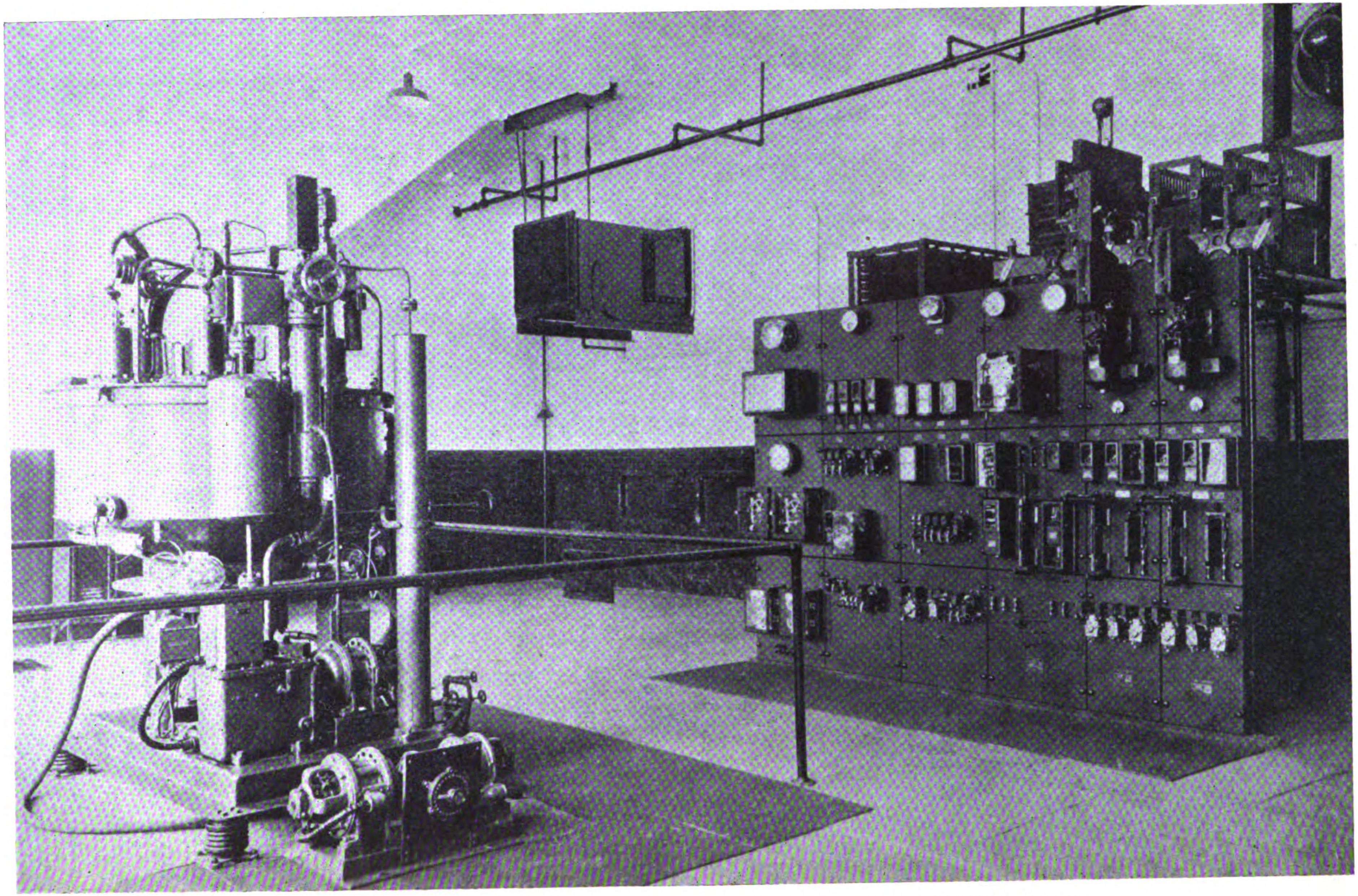

MERCURY-ARC RECTIFIER SUPPLANTS INDUCTION MOTOR-GENERATOR SETS IN LEMONT SUBSTATION

The modernization of the direct-current power supply of the Chicago & Joliet Electric Railway included the replacing of an old station by two new ones and the re-equipping of two existing stations of which the Lemont Substation is one. This view shows the rectifier, its switchboard, and in the background the radiator of the closed-cooling system for the rectifier. (*See p. 342*)

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LEAVES

A visitor in a modern power station is more impressed by the large output than by the physical dimensions of the machines. A 160,000-kw. turbine-generator does not look as large as one would anticipate. It is the development work done during the last quarter of a century on the steam turbine that has led to the high efficiencies now attained and to the extraordinarily economical use of materials, and it is thus that we are getting so high an output from each pound of metal used in construction.

Any one familiar with boiler practice even a few years ago would expect to find a whole battery of boilers to supply steam for a 160,000-kw. turbine. In the station recently visited only one and a half boiler units were required for this work. We looked into the combustion chamber of one of these boilers and were astounded to find it almost one hundred feet in height and of an area such that 100 people could dine there with ease.

On seeing one of these combustion chambers in operation, we were impressed by the tremendous amount of energy being taken from the powdered coal, and we wanted to write something about the mechanism of combustion. Then the thought occurred that combustion is rather the end than the beginning of the story.

Man can neither generate nor create energy. He can only convert one form of energy to another form of energy. The beginning of the story is—where did the coal get its energy?

All the heat, light, and power—those vital spirits of our modern civilization—that we derive from our coal-burning power stations were at one time in the great scheme of things manufactured, in a different form, in Nature's smallest but most important factories, the ***green leaves;*** and were stored away in the branches and trunks of trees and other vegetables for future use.

The green leaf is the only thing in Nature's perplexing plan that attained the art of building up organized materials from unorganized matter—of taking inert matter and building up from it a living substance. All life on the earth, both vegetable and animal, is dependent for food, and, therefore, for energy, upon the work the green leaf does.

The green leaf takes its raw materials from the air and from the soil. It is easier to say what the green leaf does with them than how it does it. A photomicrograph of a leaf section would be useful in helping an understanding by showing the arrangement of the various cells within the leaf. On the under side of a leaf there is an unnumbered host of tiny pores or stomata leading to the cells in the interior; J. Arthur Thomson tells us as many as one hundred thousand to the square inch. It is through these stomata that the leaf breathes in the carbon dioxide from the air.

The water and the all-important mineral salts are taken from the soil through an infinite number of tiny hair roots, and lifted up through the trunk of the tree, which in some cases may be 300 ft. high. No physicist or botanist has yet learned the full story of how this is accomplished. The water with the mineral salts in solution is passed along through the trunk and branches, then through the stems of the leaves into that wonderfully beautiful system of veins that we admire so much in decaying leaves. From this network of veins it is passed into the mosaic of cells. It is thus that the leaf receives its raw materials.

No chemist can do with these materials what the green leaf does.

If we were to examine the green leaf under a microscope we should see little globules or disks of green matter floating in a kind of jelly-like liquid in the cells. This is the chlorophyll, the most wonderful catalyzer in the world because by the aid of the sunlight, in some mysterious way, as yet not understood, it breaks down the carbon dioxide and with the free carbon and water and salts builds up the sugars and starches. The atoms thus rearranged are the constituents of that most complex of all things, protoplasm, which Huxley used to love to talk of as the physical basis of all life.

The chemistry of this process, which is called photosynthesis, is not completely understood. What we seem to know is this—that the leaf takes in the carbon dioxide or carbonic acid gas from the air, and the water and mineral salts from the soil, and through the agency of the chlorophyll uses the energy of the sun's rays in building these up into living matter, and in the process stores up some of the sun's energy. It is these materials and this energy that the leaf passes back into the branches and trunks of the tree, and that the ages have turned into coal, that were being converted into the energy of heat in the combustion chamber.

The green leaves breathe in carbon dioxide and exhale free oxygen. The animals breathe in free oxygen and exhale carbon dioxide. Thus life in the vegetable world and animal kingdom is maintained through mutual usefulness.

Vegetables in general and trees in particular are the world's great savings banks. It is only because of their thrift that some of the energy they have captured and stored up is available for our use, and for the maintenance, either directly or indirectly, of life in the entire animal kingdom. We owe all the bounties that the green leaf makes for us to the simple fact that vegetables and trees do not move about violently, and, therefore, do not use up all the energy they store. In other words, plants live at a low chemical level while animals live on a high chemical level. Just because they are so thrifty, plants have to support the animal kingdom.

The whole realm of Nature appears to be perpetually working in harmony, even if we cannot understand as harmonious a scheme of things that includes an everlasting fight as well as a constant service.

The tiny plant whose wide spread leaves and flowers occupy no more space than a pin's head and the giant sequoia of California with its unrivalled height and girth are breathing in unison to the tune of a Psalm of Life.

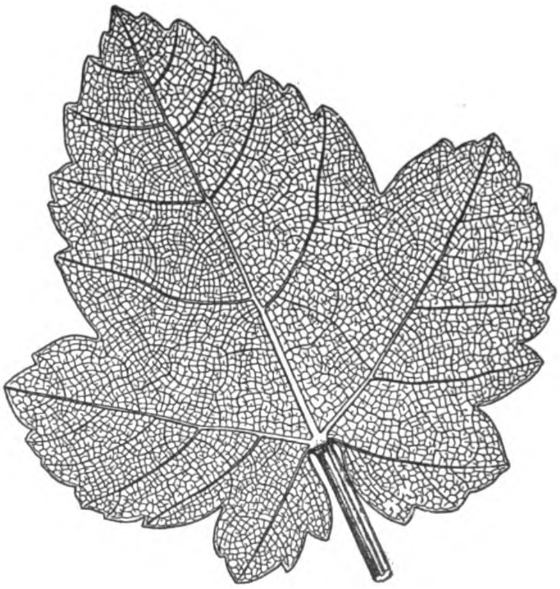
The animals eating the green leaves or devouring their neighbors to obtain their stored energy to hand on the torch of life—each of them, whether we think of the tiny shrew, the whale, or the elephant, is playing his own small part in the orchestra of life's pulsating symphony.

The insects, some feeding on flesh, some on fruits, and some on leaves, in the last analysis all get their energy of life from the thrift of the green leaf. And in return some of them carry the pollen from the anther of one bloom to the stigma of another so that the earth may continue to yield her increase.

Man, the latest word in the animal kingdom, the supreme mammal, not only takes his food and life's energy from the products of leaves but gets from the same source a large share of the fuel with which he carries on his industrial and social life.

So it is interesting when we see a 160,000-kw. turbine in operation today, and listen to its rhythmic hum, to think of the billions upon billions of green leaves that were breathing millions upon millions of years ago, as storing the energy of the sun's rays that our Public Utilities are releasing now in the form of light, heat, and power.

J. R. H.



Dimensional Analysis

Fundamentals and Applications—Changing Units—Checking Equations—Deriving Formulas—Predicting Operation of Machines from Behavior of Models—Determining the Flow of Liquids and Gases

By B. L. ROBERTSON
Formerly of the Engineering General Department, General Electric Company
Now Assistant Professor of Electrical Engineering, Pennsylvania State College

In solving engineering problems it is necessary to be as careful of the "units" in which quantities are expressed as one must be of the numerical terms. Besides the facility with which solutions are made through dimensional analysis, surprising varieties of application are found. This article presents both the elementary considerations and examples of specifications in typical problems.—EDITOR

THE subject of dimensional analysis is frequently met in one form or another, but it is probably a safe statement to say that it is not often recognized by its name. It is preliminary to a study of physics as it treats with the fundamental units by which physical quantities are measured, and is of general interest in physics and engineering, both from the standpoint of its particular applications and from that of the fundamental theory involved. The purpose of this article is to present the fundamentals of dimensional analysis and to show some of its many uses.

Most measurable physical quantities are expressed in terms of the three "fundamental" concepts of physics which are

M = mass
L = length
T = time.

The magnitude of the quantity is given by numerals, and its nature determined by various forms which these fundamental units may take. Both the magnitude and the nature of the quantity are necessary in order to give it complete meaning. To say foot-pounds, gallons, or miles, which are called derived units in that they may be expressed in terms of the above three fundamental units, tells us only the character of the quantity with which we are concerned. But when 25 foot-pounds, 10 gallons, or 2 miles is stated, the picture is complete—we also know the magnitude or measure of the quantity. The information is then sufficient.

It is often necessary and frequently of advantage to express physical quantities in symbolic form involving these three fundamental units, and when placed in such general terms the relations between them are more easily observed. The symbols M, L, and T, with their exponents, then show the manner in which the derived units are related to mass, length, and time. The resulting expression is termed a *dimensional formula* and the process by which it was obtained is known as *dimensional analysis*. Since dimensional analysis treats only with the fundamental units, no numerical coefficients appear in the formula.

All phenomena capable of being treated quantitatively are expressed in terms of certain measurable quantities, and dimensional analysis provides us with the knowledge concerning the relations existing between these quantities. It allows of determining which of the derived units, such as density, acceleration due to gravity, moment of inertia, etc., and which of the fundamental units themselves, go to make up the final result. Further than this, it also permits the determination of just how these units shall be related to each other in the ultimate expression, which in the cases we shall treat are products of the units.

Although mass, length, and time are suitable fundamental units in most physical problems, and have been chosen as the primary quantities, other primary quantities might have been selected. This has been done in some cases, and has been previously discussed. In the 1904 *Journal of Philosophy*, C. E. Magnusson suggested that the units be energy, length, and time. He states: "The selection of time and space as fundamental is inevitable, as these are respectively the forms of the inner and outer experience of our consciousness, but the use of mass as the third dimension is open to serious objection." Rather complete tables included with his treatise show that derived quantities appear in more simple form if energy replaces mass as the third dimensional unit. However, M, L, and T have been universally accepted and it is doubtful if any of them will give way to other units.

A list of the more important derived units is given in Table I for convenience of reference. We shall presently have occasion to work with some of them.

There are also dimensional constants such as the gravitational constant (G) which appears in the inverse square law expressing the force of attraction between two masses. The dimensions of G are $M^{-1} L^3 T^{-2}$. Pure numbers and dimensionless constants are quantities having zero dimensions, and do not appear in dimensional formulas. As will be later observed, this is equivalent to saying that they have the exponent zero, and therefore reduce to unity. An angle is of zero dimension for it is defined simply as the division of one length by another length regardless of whether it is given in radians, degrees, or any other angular measure.

Not all physical quantities can be expressed in terms of M, L, and T. Temperature and intensity of light are examples of those which cannot be so stated, but they are, however, related by certain constants. The thermodynamic definition of absolute temperature is such that temperature may be treated as having its own dimension, θ.

TABLE I

DIMENSIONS OF PHYSICAL QUANTITIES OF FREQUENT OCCURRENCE

Area	L^2	Momentum	MLT^{-1}
Volume	L^3	Impulse	MLT^{-1}
Density	ML^{-3}	Force	MLT^{-2}
Linear velocity	LT^{-1}	Kinetic energy	ML^2T^{-2}
Linear acceleration	LT^{-2}	Work	ML^2T^{-2}
Angle	1	Moment of inertia	ML^2
Angular velocity	T^{-1}	Pressure	$ML^{-1}T^{-2}$
Angular acceleration	T^{-2}	Power	ML^2T^{-3}

The dimensions of any of the quantities in Table I are easily obtained. As an illustration, consider force (F), which is the product of mass and acceleration.

$$\begin{aligned} F &= \text{mass} \times \text{second rate of change of} \\ &\quad \text{distance with respect to time} \\ &= M \times L/T/T \\ &= MLT^{-2} \end{aligned}$$

From this follows a second example: torque, the product of a force and a distance (lever arm).

$$\begin{aligned} T &= \text{force} \times \text{distance} \\ &= MLT^{-2} \times L \\ &= ML^2T^{-2} \end{aligned}$$

Dimensional analysis is used for several purposes, most of which can be classed in one of the following groups:

(1). Changing units.
(2). Checking equations.
(3). Deriving formulas without the use of differential equations.
(4). Application to models for the prediction of the action of full size machines from observations of the behavior of models.
(5). Application to the flow of liquids and gases in determining their flow by comparison with the known flow of a certain other liquid or gas.

The chief advantage of dimensional analysis, as stated by Bridgman, is that it is rapid. It enables us to dispense with making a complete analysis of the problem such as would be involved in writing down the equations of motion of a mechanical system. On the other hand, it does not give so complete information as might be obtained by carrying through a detailed analysis because the method does not include the evaluation of constants. This has already been mentioned. It will not permit, in one analysis, the determination of a formula if that formula is composed of two or more terms which are sums; and in some cases such formulas cannot be developed by this system, as will be explained later.

Changing Units

This use of dimensional analysis is perhaps the simplest one of the five, but occasions for its employment compose at least half of the instances in which the subject may arise. It furnishes an easy means by which conversion factors can be readily determined.

To illustrate: What is the rate of flow of 15 cubic feet per minute when expressed in gallons per hour?

$$15\,\frac{\text{cu. ft.}}{\text{min.}} = 15\,\frac{1\text{ cu. ft.}}{1\text{ min.}} = 15\,\frac{1 \times \frac{1728}{231}\text{ gal.}}{1 \times \frac{1}{60}\text{ hr.}}$$

$$= \frac{15 \times 1728 \times 60\text{ gal.}}{231\text{ hr.}}$$

$$= 6734\text{ gal. per hr.}$$

A flow of one cubic foot per minute thus corresponds to a flow of 449 gal. per hr. By similar treatment we could obtain other conversion factors, such as 88 ft. per sec. = 60 mi. per hr., one horsepower = 0.746 kw., etc.

It will be noted that cubic feet per minute and gallons per hour are dimensionally the same: *i.e.*, both are symbolized by the units L^3T^{-1}. The operation performed in the example consisted in changing the "measuring stick" by which the quantities were determined. As the measure increased, it was contained in the quantity a less number of times, and *vice versa*, this fact being recognized by an appropriate conversion factor. It is taken for granted that the elementary constants are known, such as 231 cu. in. for the volume of one gallon.

Checking Equations

It is often necessary to determine whether a derived expression or formula is dimensionally correct. A very simple case is the equation for the centrifugal force exerted by a revolving mass, which is written

$$F = \frac{Mv^2}{r} = M\omega^2 r$$

The left member is dimensionally MLT^{-2} and for its two equivalents we have, respectively,

$$\frac{Mv^2}{r} = ML^2T^{-2}L^{-1} = MLT^{-2},\text{ a force}$$

and

$$M\omega^2 r = MT^{-2}L,\text{ a force}$$

It might be pointed out that even a slight knowledge of dimensional relations might save the day for a student in mechanics who has use for this expression but is debating with himself as to whether he shall write $\frac{Mv}{r}$, $M\omega r$, or $M\omega r^2$, forms of somewhat frequent occurrence.

A different type of equation, and one of importance because of the application of its various forms, is that of the motion of the body shown in Fig. 1. The weight (*W*) vibrates at the end of the spring (*S*), its motion being damped by the plate (*D*). The equation of motion for the system is

$$M\frac{d^2x}{dt^2}+K_d\frac{dx}{dt}+K_sx+W=F(t)$$

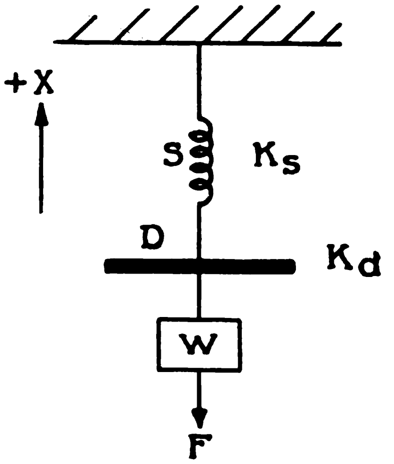


Fig. 1. The Physical Components of a System Producing Damped Vibrations

where K_d is the damping constant, expressed in pounds per unit velocity, K_s is the spring constant expressed in pounds per unit displacement of the spring, and $F(t)$ is any applied force; in general, a function of time.

Since the left member of the expression is equated to a force, all of the terms must have the dimensions of force. This can easily be checked as follows:

$$M\frac{d^2x}{dt^2}=\frac{ML}{T^2}=MLT^{-2}, \text{ a force}$$

$$K_d\frac{dx}{dt}=\frac{MLT^{-2}}{L/T}\times\frac{L}{T}=MLT^{-2}$$

$$K_sx=\frac{MLT^{-2}}{L}\times L=MLT^{-2}$$

$$W=MLT^{-2}$$

The equation is thus dimensionally correct. Justifications for such expressions often arise.

The following problem once came up in a short classroom examination and serves as an illustration in checking equations: What is the angular acceleration of a motor armature having a moment of inertia of 15 lb-ft.², when the torque applied to it is 15 ft-lb.? From the fundamental relation

$$T=I\alpha$$

we have

$$15=\frac{15}{32.2}\alpha$$

whence

$$\alpha=32.2 \text{ rad./sec.}^2$$

The point of interest here is that only one man in the class of eighteen members solved the problem correctly (the others left out 32.2), and he obtained his result by dimensionally determining that the acceleration due to gravity belonged in the equation.

Deriving Formulas

It has already been stated that dimensional analysis may be used to determine certain relations which exist between various measurable quantities. We shall find the study of this property very fascinating; for the derivation of many formulas without the use of differential equations is a surprisingly simple process when only fundamental units are used. The numerical constants which accompany the derived relations cannot, of course, be obtained by this method, but they are generally readily secured once the formulas become known.

In this study it is best to treat with specific illustrations; so we shall apply the method to certain examples, with the results of which we are already acquainted. Suppose it is desired to derive an expression such as that for the acceleration of a rotating body subjected to a torque, the period of a simple pendulum, the time of vibration of a bar, or the velocity of a wave advancing on deep water. The following steps are performed:

(*a*). Determine the quantities which are believed might possibly enter the final result.

(*b*). Write the dimensions of these quantities in the form of a product of power terms of unknown exponents, each quantity having an exponent of its own.

(*c*). Equate the unknown exponents of like fundamental units to the known exponent of the same fundamental units in terms of which the quantity to be derived is expressed.

(*d*). Solve the resulting simultaneous equations for the values of the unknown exponents and place them back in their original members. Now, when combined, these members give us the functional relationship desired.

It is possible, in many cases, to derive formulas by simple reasoning without resorting to the algebraic solution just outlined. However, such steps lead to the result more quickly. Both methods will be illustrated in the next example, which is the determination of the time of oscillation of a simple pendulum.

After a few moments thought, the reasonable assumption is made that the time of vibration (*t*) depends upon the mass (m) and length (l) of the pendulum, the amplitude (θ) of the swing, and the acceleration (g) due to gravity. Thus

$$t=f\ (m,\ l,\ \theta,\ g)$$

which dimensionally is written

$$T=f\ (M,\ L,\ 1,\ LT^{-2})$$

Analyzing the problem, we see that since the left member contains only the fundamental unit T the mass of the pendulum cannot enter the result for it cannot be combined with any other member in the function so as to disappear. It is further noticed that l and g must be combined in such a way that L is not retained. This leaves us with the possibilities of the ratios g/l or l/g, but only the latter can be used because T must appear with no negative exponents such as the first fraction would give. Also, in order that this exponent be $+1$, the quantity $\sqrt{l/g}$ must exist. The angle may or may not appear since it is dimensionless, *i.e.*, its dimension is zero. Its value is determined as that of other constants and the result of the analysis is

$$t=\sqrt{\frac{l}{g}}\phi\ (\theta)=K\sqrt{\frac{l}{g}}$$

where K is a constant to be obtained by other means.

Performing the steps indicated above, the solution becomes

$$t=f\ (m,\ l,\ \theta,\ g)$$

or

$$T=M^u\ L^v\ 1^w\ (LT^{-2})^x$$

$$=M^u\ L^{v+x}\ 1^w\ T^{-2x}$$

Equating exponents of like terms

$$u=0$$

$$v+x=0$$

$$w=0 \text{ (or any number)}$$

$$-2x=1$$

whence

$$x=-1/2$$

$$v=1/2$$

Thus

$$t=m^0\ l^{\frac{1}{2}}\ \theta^0\ g^{-\frac{1}{2}}$$

$$=K\sqrt{\frac{l}{g}} \text{ as before.}$$

Another illustration is the determination of the time (t) of longitudinal vibration of a bar. It is conceived that the period depends upon the length (l) of the bar, the density (d), and the coefficient of elasticity (E), which is force per unit area per unit deformation. Thus

$$t=f\ (l,\ d,\ E)$$

or

$$T=L^x(ML^{-3})^y\ (ML^{-1}\ T^{-2})^z$$

$$=L^{x-3y-z}\ M^{y+z}\ T^{-2z}$$

Equating exponents of like units

$$x-3y-z=0$$

$$y+z=0$$

$$-2z=1$$

whence

$$z=-1/2,\ y=1/2, \text{ and } x=1$$

The time of vibration (period) is therefore of the form

$$t=K\sqrt{\frac{dl^2}{E}}$$

In conducting experiments, it is invariably found that there are several factors which govern the action of the apparatus under test, and, generally, the bearing of any particular factor on the result is not known. Numerous experiments are conducted to determine this behavior in a definite manner. However, by the use of dimensional reasoning, it is often possible without conducting tests to find the relations of the various factors. As an example, suppose that in a certain experiment tension enters the results, the value of the exponent of which is unknown. By the process just given, this exponent may be found by dimensional analysis, thus making the experiments an orderly performance, whereas ordinarily great labor is involved in interpreting the results of many tests.

The question might be asked: Must the factors upon which the answer depends be always written in the form of products of exponential quantities? The answer is affirmative.(1)

We have seen that primary quantities are compared with each other directly, and that secondary (derived) quantities are compared indirectly through primary units. If the ratio of the numbers measuring two secondary quantities is independent of the units used in the primary quantities, in terms of which the secondary quantities are expressed, then the secondary quantities are said to possess *absolute significance of relative magnitude.* The dimensions of volumes are L^3; and to state that the ratio of one volume to another volume is 3 to 2 means absolute significance in that the size of the fundamental units does not enter this ratio. As a matter of fact, only systems which have this quality are subject to dimensional analysis.

The theorem which follows is: *Every secondary quantity which satisfies the requirement of absolute significance of relative magnitude is expressible as some constant multiplied by powers of the primary quantities.* Thus dimensional formulas are products of exponential quantities.

The following illustration may also help to answer the original question. To be specific, let us take the example of the time of longitudinal vibration of a bar. It was assumed at the start, the assumptions being based upon a certain amount of logical reasoning, that only length, density, and the modulus of elasticity entered the time of vibration of a bar. Suppose that we had not elected to write these quantities as products, but as a sum. That is

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(1) Although the proof is not given here it can be found in Bridgman's book on Dimensional Analysis.

$$t = K_1 l + K_2 d + K_3 E.$$

We now merely impose the condition that each term of this sum shall be dimensionally equal to time, and as it stands, the expression is incorrect. The coefficients (K_1, K_2, and K_3) are strictly constants and have no dimensions. Hence

$$T = L + ML^{-3} + ML^{-1}T^{-2}$$

a relation which we see is not satisfied. To correct the equation, the first term must be multiplied by T/L, the second by $M^{-1}L^3T$, and the third by $M^{-1}LT^3$. This is exactly equivalent to making each term of the last equation dimensionally identical, and in the first equation we could therefore combine the series to give what we originally started with

$$t = f(l, d, E).$$

The power products, in general, form the only solution because others which we might assume must reduce to this one. It is possible, of course, to derive formulas which do involve a series, but each term of the series would not be composed of the same derived units related in the same way as every other term. A particular instance is that of an advancing wave of water. The complete expression for the velocity of the wave is

$$v^2 = \frac{2\pi\tau}{\lambda d} + \frac{g\lambda}{2\pi}$$

where

τ = surface tension
λ = wave length
d = density
g = acceleration due to gravity

For deep water, the first term is neglected since it becomes negligible. Both terms are dimensionally the same, but are expressed by different derived units. The point to be noted here is that both terms may be obtained independently, their sum being the complete solution.

Thus far the examples, with one exception, have been made with the assumption that we knew at the outset just which quantities would be included in the final result. Such knowledge is not always available, and in many instances the quantities assumed to be contained in the answer are more than required. The doubt may then arise as to whether a correct solution is obtainable. The answer is again affirmative. This is an interesting point with which one may experiment on paper, and it will be found that if an excess of derived quantities are taken at the start, the excess terms become eliminated as the analysis proceeds. This was actually shown in the one exception mentioned.

Now one may also ask what happens when the derived quantities assumed are too few in number. Somewhat the reverse of the foregoing statements will then be true and the fundamental units will appear to the extent that the final expression is dimensionally correct. It is then left for the analyst to determine the derived quantity or quantities represented by the resulting combination of fundamental units. It is usually simpler to treat an excess of derived units than it is to build up derived units from the *left-over* fundamental units.

We now come to other important applications of dimensional analysis, with examples of its use in actual engineering problems.

Application to Models

Dimensional analysis has a very practical application in the prediction of the action of full-sized machines from the observations of the behavior of models, and in the flow of liquids and gases by comparison with the known flow of a certain liquid or gas. An example of the first use pertains to the calculation of the resistance of the air to airplane wings, and an illustration of the second is the flow of mercury in pipes. Both applications will now be considered in turn.

It is often necessary in engineering developments, after a new machine or piece of apparatus has been conceived, to know with some degree of certainty just how it will operate. The predetermination of some of its characteristics are desired in order that time, effort, and expense be saved in building the machine. Sometimes it is felt that in certain developments difficulties might arise which would practically render the apparatus useless. An entirely new attack on the method of the development would then have to be made, but until this fact were known the expense involved might be extremely great. In other cases, it might not be practical to make certain desired tests on the machine when built, but such tests could be made on the model. To exclude such expenses or to obtain knowledge concerning some particular characteristic, a miniature duplicate, so to speak, of the machine is built and from its action the operation of the large one may be predicted.

The design of the model makes use of the *Principle of Similitude* which is stated: *The fundamental entities out of which the physical universe is constructed are of such a nature that from them a miniature universe could be constructed similar in every respect to the present universe.* This axiomatic principle was first stated by Professor R. C. Tolman in the *Physical Review* of 1914. It is a generalization which comes from observation and is not capable of mathematical proof.

Applying the principle to the action of models, it is possible to determine what the mass, size, velocity, etc., of a model must be to represent the actual machine under all conditions. The motion of the machine will be given by the equation

$$f' = m' \frac{d^2x'}{dt'^2}$$

and that of the model by

$$f = m\frac{d^2x}{dt^2}$$

The forces, masses, distances, and times are related by

$$f = Ff'$$
$$m = Mm'$$
$$x = Xx'$$
$$t = Tt'$$

in order that the machine and its model remain geometrically similar during their motions.

Thus, for the model

$$Ff' = \frac{MX}{T^2} m' \frac{d^2x'}{dt'^2}$$

or

$$f' = \frac{MX}{T^2F} m' \frac{d^2x'}{dt'^2}$$

It is seen that if

$$\frac{MX}{T^2F} = 1$$

the equation for the motion of the full-size machine is obtained, so the moving forces of the model are then in the ratio

$$F = \frac{MX}{T^2}$$

to those of the machine.(2)

A simple example will illustrate the fact just brought out. Assume that a model elevator is to be built and tested to predetermine the operation of the full-sized elevator. The mass of the small car is to be 0.04 times the mass of the ordinary elevator car; the unit of length 0.2, and the unit of time 0.2 of the ordinary second. It is desired to know what force in pounds in the foot-pound-second system will be required to accelerate the car in five of the model seconds to a velocity of two feet per second in our present system. The weight of the average elevator car, including counterweights, may be assumed to be 2000 lb.

We thus have

$$m = 0.04\ m'$$
$$x = 0.2\ x'$$
$$t = 0.2\ t'$$

From the relation previously developed

$$\frac{mx}{t^2f} = \frac{m'x'}{t'^2f'}$$

whence

$$f = \frac{mx}{t^2}\ \frac{t'^2f'}{m'x'}$$
$$= \frac{0.04\ m'}{m'}\ \frac{0.2\ x'}{x'}\ \frac{t'^2}{0.04\ t'^2} f'$$
$$= 0.2 f'$$

Since f' in the foot-pound-second system is equal to 124.3 lb.

$$f = 24.86 \text{ lb.}$$

the force required to accelerate the model elevator car.

Application to the Flow of Liquids and Gases

More complicated problems than those just given arise in the study of theoretical aëronautics. Heretofore it has been impossible to derive, by means of differential equations, the resistance which the air offers to the wings of an airplane. Dimensional analysis, however, provides a solution by which, with the aid of small models, this resistance can be determined.

The resistance that the air offers a body moving within it depends upon the shape, size, and speed of the body, and upon the density and viscosity of the air. These factors with their symbols and "dimensions" are listed as follows:

Shape (given by scale drawing)	
Size (length of different parts).....	L
Speed of the body (v)..............	L/T
Density of the air (ρ)............	M/L^3
Viscosity of the air (μ)..........	M/LT

Viscosity is defined as the tange[illegible] or shearing force exerted upon unit area of eitl[illegible] of two horizontal planes placed at unit distance apart, in the viscous substance, one of the planes being fixed and the other moving at unit velocity. Its dimension readily follows from this definition.

The resistance R is thus written

$$R = f\ (v,\ l,\ \rho,\ \mu)$$
$$= K\ v^w\ l^x\ \rho^y\ \mu^z$$

and in dimensional form

$$MLT^{-2} = (LT^{-1})^w L^x\ (ML^{-3})^y\ (ML^{-1}T^{-1})^z$$
$$= L^{w+x-3y-z}\ T^{-w-z}\ M^{y+z}$$

Equating exponents of like units and expressing w, x, and y in terms of z, the right member takes the form

$$v^{2-z}\ l^{2-z}\ \rho^{1-z}\ \mu^z = \rho\ v^2\ l^2 \left(\frac{vl\rho}{\mu}\right)^{-z}$$

whence

$$R = \rho\ v^2\ l^2\ f\left(\frac{vl\rho}{\mu}\right) \qquad (1)$$

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(2)These equations in a much longer treatment are discussed in Glazebrook's Dictionary of Physics; but they suffice here for our purpose.

The function f depends upon the type of flow. If the subscript 1 denotes quantities pertaining to the model, and the subscript 2 denotes quantities pertaining to the large airplane which the model is to represent, the same type of air flow, *i.e.*, the same shape eddies, etc., will occur about both model and airplane when

$$\frac{v_1\, l_1\, \rho_1}{\mu_1} = \frac{v_2\, l_2\, \rho_2}{\mu_2} \tag{2}$$

This permits, then, by proper adjustments of the conditions under which the model operates, the determination of R_2, since the ratio of the functions disappears. Thus

$$R_2 = R_1\, \frac{\rho_2\, v_2^2\, l_2^2}{\rho_1\, v_1^2\, l_1^2} \tag{3}$$

From this we observe that it is possible from experiments on a small model moving with a high velocity to obtain results which are exactly similar to those which would be obtained on a large airplane moving at a lower velocity. Similarly, a small model can be tested in water, which has a density and viscosity very different from air, and the prediction made for the motion of other models in air. Dimensional analysis therefore solves a problem which can be treated by differential equations only in a most difficult manner.

The frictional force met in the study of the turbulent flow of liquids through pipes is represented by the expression

$$F = K\, f\, \rho\, v^2\, l\, d$$

which is known as the Fanning equation. The terms are

= a constant to care for units
friction factor
density of the liquid
v = velocity of the liquid
l = length of the pipe
d = diameter of the pipe

and we can rearrange the equation to read

$$F = K_1\, f\, \rho\, v^2\, l^2$$

since l and d are linear dimensions.

About seventy years ago Stokes, in mathematically treating the flow of liquids in pipes, determined that this friction factor (f) is a function of four variables, the velocity, density, and viscosity of the liquid, and the diameter of the pipe through which the liquid flows; *i.e.*:

$$f = \phi\left(\frac{\rho\, v\, d}{\mu}\right)$$

It is readily recognized that the Fanning equation is now of exactly the same form as the one previously derived for the flow of air about an object, since

$$F = K_1\, \rho\, v^2\, l^2\, \phi\left(\frac{\rho\, v\, d}{\mu}\right)$$

This equation applies to all types of flow. For streamline motion

$$\phi\left(\frac{\rho\, v\, d}{\mu}\right) = \frac{\mu}{\rho\, v\, d}$$

and

$$F = K_2\, \mu\, v\, l$$

As before, if the subscript 1 denotes the quantities pertaining to one liquid, and the subscript 2 denotes the quantities pertaining to a second liquid, both liquids will have the same type of flow when

$$\frac{v_1\, l_1\, \rho_1}{\mu_1} = \frac{v_2\, l_2\, \rho_2}{\mu_2} \tag{2}$$

The practical application of this relation is demonstrated in an actual problem which came some little time ago to the office with which the writer was connected, involving the determination of loss in pressure head, due to the flow of mercury in pipes. Since there were no tables for such flow, it was necessary to use tables for the friction of water flowing in pipes and interpret the results for mercury by the Principle of Similitude. Water flowing through a pipe wets it, and therefore it is always assumed that the layer of water next to the tube stands still; *i.e.*, all the shearing takes place in the water. In applying the Principle of Similitude, it is necessary to assume that the shearing takes place in the mercury also. There may be some doubt as to the validity of this assumption as mercury has a negative capillary action. However, the assumption gives a conservative result because if the mercury slips along the tube, the pressure head lost will be less.

The problem was to determine the head lost when mercury flowed through a tube six feet long and one-half inch in diameter with a velocity of ten feet per second.

Letting the subscript 2 represent quantities for mercury, and the subscript 1 denote quantities for water, we have

$$\frac{F_2}{F_1} = \frac{\rho_2\, v_2^2\, l_2^2}{\rho_1\, v_1^2\, l_1^2} \tag{3}$$

in which the ratio of the functions is unity.

Note that the constants now drop out since both forces are expressed in the same units. The values of ρ are known and μ is determined as 0.0156 for mercury and 0.01006 for water, 20 deg. C. being chosen as normal temperature. It is quite convenient to look up a velocity of 20 ft. per sec. in the tables for the friction factor of water flowing in pipes, and with the given velocity for mercury of 10 ft. per sec., it is thus determined from the functional relation of Equation (2) that

$$l_1 = 4.35\, l_2$$

This means that the length of the water pipe would be 26.15 ft. and its diameter 2.18 in. in order that water flowing through it have the same type of flow as mercury passing through the smaller pipe.

From the formula for the pressure drop due to water flowing in a pipe, the friction head lost is

$$h_f = f\frac{lv^2}{d\,2_g}$$

in which

f = friction factor
d = pipe diameter

Interpolation in tables gives a value of 0.022 for f, whence

$$h_f = 19.7 \text{ ft. of water}$$

The total friction force is then

$$F_1 = 31.8 \text{ lb.}$$

and the force necessary to cause the specified flow of mercury is found as

$$F_2 = 5.7 \text{ lb.}$$

For the particular pipe in question, this force corresponds to a head of 4.97 ft. of mercury. This figure checked test results which were later obtained.

The value of dimensional analysis lies in its practical applications. It has a definite place in physics and engineering, as shown by the examples given in this article, and it is interesting to know that the analysis is used to a considerable extent at the Bureau of Standards. The particular problem involving the loss of pressure head was solved in such a novel manner it was felt that many others would be interested in the further relations of the fundamentals of dimensional analysis to actual engineering problems. It is hoped that this simple treatment will give a clearer understanding of a subject which is very often met by engineers, but frequently not recognized.

Byrd Expedition is Welcomed in Long-distance Radio Conversation

IN what was undoubtedly the longest talking circuit ever established, Adolph S. Ochs and others in Schenectady (N. Y.) chatted with Rear Admiral Richard E. Byrd and Russell Owen, at Dunedin (New Zealand), on March 11 (March 12 in New Zealand), a few hours after the Byrd expedition returned to civilization from Antarctica.

The voices of the Schenectady speakers were carried direct to Dunedin, 9320 miles, by W2XAF, one of the short-wave stations of the General Electric Company. The voice of Rear Admiral Byrd reached the United States through an elaborate hook-up which involved the use of land wires, submarine cable, a long-wave broadcast transmitter, and a short-wave transmitter. From Dunedin the voice was carried by land wire and cable to Wellington (N. Z.), a distance of 500 miles. At Wellington, Station 2YA, operating on 420 meters, carried the voice 1200 miles to Sydney (Australia), where 2ME, the short-wave station of the Amalgamated Wireless Australasia Limited, rebroadcast the signal direct to the receiving laboratory of the General Electric Company, eight miles outside of Schenectady, in the town of Glenville (N. Y.).

WGY, at Schenectady, and forty broadcasting stations throughout the United States in a great coast-to-coast network of the National Broadcasting Company, gave the conversations to millions throughout the country. Europe heard the broadcast through the medium of W2XAD, another short-wave station of the General Electric Company. The signal was received in England and in Germany. Stuttgart (Germany) picked up the signal and passed it on to a great chain of German stations, and for fifteen minutes the conversations were heard throughout the German Republic. Long-wave stations in New Zealand and Australia also broadcast both sides of the conversations. With the possible exception of the rebroadcast of the address of King George, opening the Naval Conference in London, probably no broadcast on record has had wider distribution.

Those who talked with Rear Admiral Byrd and Russell Owen in addition to Mr. Ochs, publisher of the *New York Times*, were Arthur Hays Sulzberger, vice-president of the *New York Times*, Martin P. Rice, manager of the Publicity Department of the General Electric Company, and Emanuel Cohen, editor of the *Paramount News Reel*.

Paramount News Reel made a picture and sound record of the great radio experiment and a complete sound record was made by the General Electric Company in the Research Laboratory at Schenectady.

For a year, beginning March 9, 1929, W2XAF broadcast fortnightly radio programs to the Byrd expedition while it was at "Little America" and during the weeks it was on the water returning to New Zealand. These programs were arranged by the Publicity Department and the impressive conversations on March 11, this year, carried on through the coöperation of this and the Radio Transmitter Department of the General Electric Company, marked an historic culmination of the Byrd broadcasts.

Directed Quantities in a Plane Space

ELEMENTARY OPERATIONS

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The author advocates the use of vectorial methods for solving both mechanical and electrical problems. He describes the vectorial method in great detail giving full consideration to all factors separately. He concludes by showing some worked-out applications to mechanical problems.
—EDITOR

THE application of vectorial methods to mechanical and electrical problems leads to a great simplification in the general treatment of these problems. Yet, only the so-called symbolic method is widely used in electrical engineering. Mechanical engineers practically never use vectorial methods. This is partly due to the lack of simple and easily accessible sources of information. It is not necessary for a beginner to start with the study of the three-directional vector analysis. In most mechanical problems the motion is uniplanar, so that a wide field of application is open to vectorial methods confined to a two-directional (plane) space. And the analytical processes of the symbolic method are just as applicable to mechanical problems as to electrical. In the present article, the simplest and most useful operations, those of forming various products of directed quantities in a plane space are presented on the basis of the idea of generalized direction, and the direction in general is treated as a quantity. This removes the traditional barrier between the symbolic method and the ordinary vectorial method. Complex, vectorial, and point quantities all appear as merely different aspects of the same two-directional quantities, and there is no longer any distinction between "real" and "imaginary" quantities.

The underlying general principles of the algebraic treatment of physical quantities, as distinct from the numerical system with "units," have been presented elsewhere.(1)

Generalized Directions

The familiar geometric direction—the direction of a line in geometric space—is the direction in which the length of the line increases, nothing else being changed. In other words, the direction of a line is the direction of its growth. Similarly, we may invest various physical quantities, *e.g.*, temperature, density, etc., with their own *non-geometric* directions. The generalized direction of a physical quantity is the "direction" in which its magnitude grows. This direction can not be identified with any geometric direction; it is outside the geometric space.

Physical quantities of various designations are distinct, and there is no transition, *i.e.*, continuous change, from one to any other. It must be assumed, therefore, that the generalized direction of any distinct physical quantity is entirely different from the directions of all other quantities. There can be no component of one quantity in the direction of any other. As a kind of consistent definition it may be stated that all these directions are *normal* to each other. Geometric directions are particular cases of the generalized directions. However, there may be transition from one geometric direction to others. The generalized space occupied by a simple physical quantity, *e.g.*, temperature, is essentially a one-directional space. The space occupied by geometric directions may be one-, two-, or three-directional. In a plane space, two *reference* directions may be selected arbitrarily, one normal to the other, and thus made distinct; all the remaining directions in the same space are in transition. It will be seen that this distinction does not belong exclusively to the geometric space. There are physical quantities which may have direction varying in a two-directional generalized space.

Direction as a Quantity

A physical quantity complete may be considered a simple product of its magnitude and direction. Then, the direction itself becomes a quantity. Since the physical nature is associated with the magnitude, the direction has no physical nature.

The magnitude of a quantity is that which makes a definite quantity greater or less than another definite quantity of the same nature and direction. There is nothing numerical about the magnitude; it is a property of a definite quantity and is independent of any measurement. Numbers in physics are abstract ratios. In the ratio of two definite quantities of the same nature and direction, both the direction and the physical nature disappear, and there remains the ratio of the two magnitudes, an abstract number. A number has no physical nature and no generalized direction but has a numerical magnitude. These numbers are always incommensurable with unity, and only approximately can they be represented by integers or fractions. The ratio of a magnitude to an arbitrarily chosen *basic* amount of the same nature is called the *percentage*. The only instance when an integer, unity, arises, is in the ratio of a quantity to itself. In such a case the percentage is 100 per cent or unity. The simple product of a number and a direction is a *directed number*. It follows that a direction as a quantity is a directed number of the magnitude unity.

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(1) "Dimensional System of Notation," by V. Petrovsky, GENERAL ELECTRIC REVIEW, Vol. 27, November, 1925, pp. 757-761.
See also the article by Mr. Robertson on p. 207 of this issue.—EDITOR.

Scalar Quantities

Although all physical quantities have their generalized directions, only those directions are recognizable which are contained in the space considered. The restriction of the space to a certain number of distinct directions leaves no place for the remaining ones. Thus, the direction of a quantity which is normal to the space considered has to be ignored. Then, the quantity retains all its physical nature but loses its essentially directed character and is called a *scalar* quantity. A familiar case, when a definite geometric direction is ignored, is that of angular velocity in a uniplanar motion. The angular velocity is normal to the plane of the motion, and for this reason cannot have any recognizable direction in that plane. Therefore, as long as the space considered is the two-directional space of the motion, the angular velocity is a scalar quantity. A plane area in a three-directional space is a directed quantity having the direction of its normal. The same area considered in a plane space is a scalar quantity.

Whenever it is said that a physical quantity, *e.g.*, a force, has a geometric direction, it is meant that the generalized direction of the quantity is ignored, as being normal to the geometric space, and a new, geometrically directed, quantity is formed as a simple product of the scalar quantity and the given geometric direction. It is not at all necessary that a force should have a geometric direction. For example, a force load due to a uniform pressure on a spherical surface is a certain amount of force, and has its own generalized direction, but cannot be associated with any geometric direction.

Two-directional Quantities

Besides two-directional quantities in geometric plane space there are other quantities that are not reducible to a simple product of one definite generalized direction and a scalar magnitude. For example, the total power of an alternating current in a given circuit is made up of two components: the active power and the reactive power, and each component may vary separately. Both are of the same physical nature $[f\, l\, t^{-1}]$, but the generalized direction of the reactive power is normal to the generalized direction of the active power. This merely means that the reactive power can not have any active component and *vice versa*. Thus, the resultant quantity is two-directional. There is certainly a generalized direction of the resultant quantity; but that direction is not a definite fixed direction but is in transition between the two component directions, just as in a geometric two-directional space a variable direction is in transition between the two chosen reference directions. This permits a geometric representation of such directed quantities as have both components of the same physical nature. The method of representation consists in constructing a geometric image of the two-directional space considered. The chosen reference directions in the plane space represent the directions of the two component quantities. It remains to represent the magnitudes of the components by linear magnitudes. A power can not be made equal to a length, but the percentage of a power may be equal to the percentage of a length. It is sufficient, therefore, to select convenient basic amounts of power and length, and to represent the percentages to scale. Obviously, the actual linear length that represents a percentage is of no importance. Thus, ultimately, the representation is not by geometrically directed lines but by geometrically directed numbers. Since the resultant quantity has a direction in the space considered, that direction can not be ignored, and the quantity can not be called scalar, even when one of the components happens to be equal to zero.

A Plane Space

In a geometric image of a two-directional generalized space or of any given geometric plane space, one of the two reference directions may be selected arbitrarily. A direction is not confined to any definite line; in a set of parallel lines the direction is the same everywhere. Still, in order to represent the magnitudes of the components from one common point, the *origin* is selected arbitrarily. Then, all representative directions may be considered as *localized* at the origin. A change of a direction is an angular displacement in the plane space. The positive sense of angular displacement is a matter of convention, but this convention must be adhered to consistently. The direction normal to a given direction is that obtained from it by an angular displacement $+\pi/2$. Obviously, the direction normal to the second will not be identical with the first but opposite to it. Thus, selecting the two reference directions it is necessary to distinguish them as the first and second in order.

It is customary and convenient to designate directed quantities by heavy type in printing and by underlined letters in writing. The same letters in light type or not underlined represent the magnitudes alone, *i.e.*, the corresponding scalar quantities. A direction as a quantity will be preferably designated by a Greek letter. Thus,

$$\mathbf{A} = A\,\boldsymbol{\alpha}$$

Because of the established usage, an exception is made for the reference directions. The first reference direction is designated by $\boldsymbol{i}$, the second by $\boldsymbol{j}$. These are the first two of the $\boldsymbol{i}, \boldsymbol{j}, \boldsymbol{k}$ of the three-directional vector analysis; the direction $\boldsymbol{k}$ being the direction normal to the plane of $\boldsymbol{i}$ and $\boldsymbol{j}$. When the problem is limited to a plane space, the direction $\boldsymbol{k}$ is ignored, and all quantities directed in the $\boldsymbol{k}$ direction are considered scalar.

Products

In dealing with physical quantities the ordinary arithmetic multiplication is out of place, because there are no numbers to multiply. Even the term multiplication can not be used. We do not multiply one quantity by another but we form their product. Any operation that conforms with the distributive law is an operation of forming a product. The arithmetic multiplication is only a particular instance, and appears in its place in all final calculations, whenever it is necessary to evaluate a product of percentages.

Various types of products may be formed. They are not invented to fill a mathematical scheme. New types of products are created whenever the necessity arises to represent certain physical relations.

The simple product, *i.e.*, the ordinary algebraic product, does not involve any directional relations. Therefore, a simple product may not have more than one directed factor, and the direction of that factor remains unchanged in the product. Whenever there are two or more directed factors, they may form various types of special products which have to be defined.

Since any directed quantity is a simple product of a scalar quantity and a direction, it will be sufficient, when deriving formulas for special products, to consider the directions alone. Any product of two or more directed quantities is made up of the two factors; one is the simple product of the scalar magnitudes involved, the other is the proper product of the directions.

Formal Product

The characteristic of the formal product is that the directions are interpreted as operations of rotation. The *rotational angle* is the angle which a direction makes with the first reference direction. Let any two directions $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ be considered, making with the first reference direction angles ϕ and ψ respectively. The relation

$$\boldsymbol{\alpha}\boldsymbol{\beta}=\boldsymbol{\gamma}$$

may be interpreted as the operation of rotation through the angle ϕ, performed on the direction $\boldsymbol{\beta}$. The result is a new direction $\boldsymbol{\gamma}$ making an angle $\phi+\psi$ with the first reference direction. The operation conforms with the distributive law, and therefore is a type of product, in which $\boldsymbol{\alpha}$ appears again as a quantity. Obviously, the order of the factors may be inverted without affecting the result. It is seen from the relation

$$\boldsymbol{\alpha}\boldsymbol{i} = \boldsymbol{i}\boldsymbol{\alpha} = \boldsymbol{\alpha}$$

that the direction $\boldsymbol{i}$, *as a factor in a formal product*, is equivalent to unity, and may be inserted or cancelled at will.

In the convenient notation of the symbolic method,

$$\boldsymbol{\alpha} = \underline{|\phi} \qquad \boldsymbol{\beta} = \underline{|\psi}$$

$$\boldsymbol{\alpha}\boldsymbol{\beta} = \underline{|\phi}\,\underline{|\psi} = \underline{|\phi+\psi}$$

Here, however, the symbol $\underline{|\phi}$ does not represent any recognizable function of ϕ but is merely a symbol of an operation. It is desirable to represent the direction as a function of the rotational angle, so that this function can enter formally into algebraic operations. Obviously, the function will be exponential. Let, provisionally, as a definition,

$$\boldsymbol{\alpha} = \boldsymbol{z}^{\phi}, \quad \boldsymbol{\beta} = \boldsymbol{z}^{\psi}, \text{ etc.}$$

where $\boldsymbol{z}$ is an unknown constant to be determined. The heavy type indicates that this constant can not be an abstract number. With this notation,

$$\boldsymbol{\alpha}\boldsymbol{\beta} = \boldsymbol{z}^{\phi}\boldsymbol{z}^{\psi} = \boldsymbol{z}^{\phi+\psi}$$

If $\phi = 1$,

$$\boldsymbol{z}^{1} = \boldsymbol{z} = \underline{|1}$$

Therefore, $\boldsymbol{z}$ is a direction making an angle equal to unity with the first reference direction; and any power of $\boldsymbol{z}$ is a direction. Then

$$\boldsymbol{z}^{\pi} = -\boldsymbol{i}$$

But, algebraically,

$$\boldsymbol{i}\,e^{\sqrt{-1}\,\pi} = \boldsymbol{i}\,(\cos\pi + \sqrt{-1}\sin\pi) = -\boldsymbol{i}$$

Hence,

$$\boldsymbol{z}^{\pi} = \boldsymbol{i}\,\boldsymbol{z}^{\pi} = \boldsymbol{i}\,e^{\sqrt{-1}\,\pi}$$

It appears now that $e^{\sqrt{-1}}$ is also a direction:

$$\boldsymbol{e}^{\sqrt{-1}} = \boldsymbol{z} = \underline{|1}$$

so that the original definition becomes

$$\boldsymbol{\alpha} = \boldsymbol{e}^{\sqrt{-1}\,\phi}$$

Then,

$$\boldsymbol{j} = \boldsymbol{e}^{\sqrt{-1}\,\pi/2} = \cos\frac{\pi}{2} + \sqrt{-1}\sin\frac{\pi}{2} = \sqrt{-1}$$

It appears again that $\sqrt{-1}$ is also a direction:

$$\sqrt{-1} = \boldsymbol{j}$$

Finally,

$$\boldsymbol{\alpha} = \boldsymbol{e}^{j\phi} = \boldsymbol{i}\,\boldsymbol{e}^{j\phi}$$

The factor $\boldsymbol{e}^{j\phi}$ is called the *direction factor*. The heavy type of j is not necessary, since the form indicates the meaning. Thus, any directed quantity can be represented as a simple product of its scalar magnitude and a direction factor.

For any two directed quantities in a plane space

$$\boldsymbol{A} = A\,\boldsymbol{e}^{j\phi} \quad , \quad \boldsymbol{B} = B\,\boldsymbol{e}^{j\psi}$$

the *formal* product is defined as

$$\boldsymbol{A}\boldsymbol{B} = A\,B\,\boldsymbol{e}^{j(\phi+\psi)} \qquad (1)$$

i.e., in a formal product the directions are expressed as the direction factors, and the operation is performed algebraically as in a simple product. The order of the factors is immaterial.

The formal product may be formed with any number of factors. The "power" of a directed quantity in a plane space is always understood as a formal product:

$$\boldsymbol{A}^2 = \boldsymbol{A}\,\boldsymbol{A} = A^2\,\boldsymbol{e}^{j2\phi}$$

Two directed quantities in a plane space, equal in magnitude and situated symmetrically about the first reference direction, are called *conjugate* to each other. A quantity conjugate to a given quantity will be distinguished by a bar above the letter:

$$\boldsymbol{A} = A\,\boldsymbol{e}^{j\phi}$$

$$\overline{\boldsymbol{A}} = A\,\boldsymbol{e}^{-j\phi}$$

To form a conjugate, it is not necessary first to express the quantity in the standard form; in any expression it is sufficient to change the algebraic sign of $\boldsymbol{j}$ throughout. The formal product of two conjugate quantities has the first reference direction:

$$\boldsymbol{A}\overline{\boldsymbol{A}} = A^2\,\boldsymbol{i}$$

The formal reciprocal of a directed quantity has the conjugate direction:

$$\frac{1}{\boldsymbol{A}} = \frac{1}{A\boldsymbol{\alpha}} = \frac{1}{A}\overline{\boldsymbol{\alpha}} = \frac{1}{A^2}\overline{\boldsymbol{A}}$$

The formal product depends essentially on the relations of the factors to the reference directions. For quantities directed in an actual geometric space, the products required by the physical relations are independent of the selection of the reference directions. In such cases new types of products are applicable which may be called natural products in distinction from the formal product.

Inner Product

The inner product is created to represent physical products in which one directed quantity is effective to the amount of its component in the direction of the other. For example, when a geometrically directed force is doing work in a displacement at an angle with its direction, the work is done in the total displacement by the component of the force in the direction of the displacement. Or, it may be considered just as well that the work is done by the total force in the component of the displacement in the direction of the force. Let any two directed quantities in a plane space be

$$\boldsymbol{A} = A\,\boldsymbol{\alpha} = A\,\boldsymbol{e}^{j\phi}, \quad \boldsymbol{B} = B\,\boldsymbol{\beta} = B\,\boldsymbol{e}^{j\psi}$$

For physical relations of the above type, the *inner* product of $\boldsymbol{A}$ and $\boldsymbol{B}$ is defined as

$$\boldsymbol{A}\cdot\boldsymbol{B} = A\,B\cos(\psi-\phi) \qquad (2)$$

The notation of the inner product is a dot between the two letters. The reference directions are immaterial. The result is a new kind of physical quantity and its generalized direction has no place in the space considered; therefore, the result is a scalar quantity. The order of the factors is immaterial.

The inner product of two directions is the cosine of the angle between them:

$$\boldsymbol{\alpha}\cdot\boldsymbol{\beta} = \boldsymbol{e}^{j\phi}\cdot\boldsymbol{e}^{j\psi} = \cos(\psi-\phi)$$

The inner product of a direction and a directed quantity is the scalar magnitude of the component of the quantity in that direction:

$$\boldsymbol{\alpha}\cdot\boldsymbol{B} = B\cos(\psi-\phi)$$

In particular, the magnitude of the components of $\boldsymbol{A}$ in the two reference directions are

$$A' = \boldsymbol{i}\cdot\boldsymbol{A} = A\cos\phi$$

$$A'' = \boldsymbol{j}\cdot\boldsymbol{A} = A\sin\phi$$

from which

$$A = +\sqrt{A'^2 + A''^2}$$

$$\tan\phi = \frac{A''}{A'}$$

The inner product of a directed quantity with itself is the square of the scalar magnitude:

$$\boldsymbol{A}\cdot\boldsymbol{A} = A^2$$

The inner product of a direction with itself is unity:

$$\boldsymbol{\alpha}\cdot\boldsymbol{\alpha} = 1$$

In particular,

$$\boldsymbol{i}\cdot\boldsymbol{i} = 1 \qquad \boldsymbol{j}\cdot\boldsymbol{j} = 1$$

By definition of the reciprocal in general, the inner product of a directed quantity with its inner reciprocal must be equal to unity:

$$\boldsymbol{A}\cdot(\boldsymbol{A}^{-1}) = 1$$

Therefore, the *inner reciprocal* of a directed quantity has the same direction as the original quantity:

$$(\boldsymbol{A}^{-1}) = \frac{1}{A}\boldsymbol{\alpha} = \frac{1}{A^2}\boldsymbol{A}$$

The parenthesis is introduced to distinguish the inner reciprocal from the formal reciprocal which has the same magnitude but the conjugate direction.

The inner product is always zero, when one of the factors is normal to the other. In particular,

$$\boldsymbol{i}\cdot\boldsymbol{j} = 0$$

In terms of the components taken along any set of reference directions; if

$$\boldsymbol{A} = A'\,\boldsymbol{i} + A''\,\boldsymbol{j}$$

$$\boldsymbol{B} = B'\,\boldsymbol{i} + B''\,\boldsymbol{j}$$

$$\boldsymbol{A}\cdot\boldsymbol{B} = A'B' + A''B'' \qquad (3)$$

The other familiar names of inner product are: dot product, direct product, scalar product. It will be seen that the last term is not suitable in a plane space, since the other natural product is also a scalar quantity.

Outer Product

The outer product is created to represent physical products in which one directed quantity is effective to the amount of its component in the direction normal to the other quantity. For example, two geometrically directed lines in a plane space, when localized at the origin, constitute two sides of a parallelogram. The area of this parallelogram is proportional to the magnitude of each line separately. However, in forming the magnitude of the area, the second line is effective only to the amount of its component in the direction normal to the first line. In this case, it is not immaterial which one of the two quantities enters as a component, because the components in the directions of the two normals are always opposite in sign. Therefore, the two factors have to be distinguished as the first and second in order. Let any two directed quantities in a plane space be

$$\mathbf{A} = A\boldsymbol{\alpha} = A\,\boldsymbol{e}^{j\phi} \quad , \quad \mathbf{B} = B\boldsymbol{\beta} = B\,\boldsymbol{e}^{j\psi}$$

For physical relations of the above type, the *outer* product of $\mathbf{A}$ and $\mathbf{B}$ is defined as

$$\mathbf{A} \times \mathbf{B} = A\,B \sin(\psi - \phi) \tag{4}$$

The notation of the outer product is a small cross between the letters. Then,

$$\mathbf{B} \times \mathbf{A} = B\,A \sin(\phi - \psi) = -\,\mathbf{A} \times \mathbf{B}$$

Thus, the change of the order of the factors changes the algebraic sign of the outer product. The reference directions are immaterial. The result is a new kind of physical quantity and its generalized direction has no place in the space considered; therefore, the result is a scalar quantity. This is not so in three-directional space. The outer product of two lines is the area of the parallelogram which has its geometric direction normal to its plane. This direction is still in the three-directional space; therefore, in three-directional space, the result is a directed quantity.

The outer product of two directions is the sine of the angle that the second makes with the first:

$$\boldsymbol{\alpha} \times \boldsymbol{\beta} = \boldsymbol{e}^{j\phi} \times \boldsymbol{e}^{j\psi} = \sin(\psi - \phi)$$

The outer product of a direction and a directed quantity is the scalar magnitude of the component of the quantity in the direction normal to that direction:

$$\boldsymbol{\alpha} \times \mathbf{B} = B \sin(\psi - \phi)$$

In particular,

$$\boldsymbol{i} \times \mathbf{A} = A \sin\phi$$

The outer product is always zero when the two factors have the same direction:

$$\mathbf{A} \times \mathbf{A} = 0$$

In particular,

$$\boldsymbol{i} \times \boldsymbol{i} = 0 \qquad \boldsymbol{j} \times \boldsymbol{j} = 0$$

The outer product of a directed quantity with another quantity normal to it is the product of the scalar magnitudes. If $\psi = \phi + \pi/2$, *i.e.*, $\boldsymbol{\beta} = \boldsymbol{j}\,\boldsymbol{\alpha}$,

$$\mathbf{A} \times \mathbf{B} = A\,B$$

In particular,

$$\boldsymbol{i} \times \boldsymbol{j} = 1 \qquad \boldsymbol{j} \times \boldsymbol{i} = -1$$

There are two *outer reciprocals* of the opposite algebraic signs:

$$[A^{-1}]' = -\frac{1}{A}\boldsymbol{j}\,\boldsymbol{\alpha} = -\frac{1}{A^2}\boldsymbol{j}\,\mathbf{A}$$

$$[A^{-1}]'' = \frac{1}{A}\boldsymbol{j}\,\boldsymbol{\alpha} = \frac{1}{A^2}\boldsymbol{j}\,\mathbf{A}$$

in the direction normal to the original quantity. However, they find no application.

In terms of the components taken along any set of reference directions; if

$$\mathbf{A} = A'\,\boldsymbol{i} + A''\,\boldsymbol{j}$$

$$\mathbf{B} = B'\,\boldsymbol{i} + B''\,\boldsymbol{j}$$

$$\mathbf{A} \times \mathbf{B} = A'B'' - A''B' \tag{5}$$

The other familiar names of outer product are: cross product, skew product, vector product. The last term is not suitable in a plane space.

Triple Product

A product of three directed quantities, two of them in a formal product which then enters as a factor in an inner or outer product with the third quantity, will be called a triple product. The term is used in three-directional vector analysis, although for a different purpose. There is no formal product in three-directional space. Triple product is scalar but depends on the relations of the factors to the reference directions. No new operations are involved. Yet, certain relations are of general character and are useful in applications. Let any three directed quantities in a plane space be

$$\mathbf{A} = A\,\boldsymbol{e}^{j\phi} \quad , \quad \mathbf{B} = B\,\boldsymbol{e}^{j\psi} \quad , \quad \mathbf{C} = C\,\boldsymbol{e}^{j\chi}$$

On the basis of the inner product,

$$(\boldsymbol{e}^{j\phi}\,\boldsymbol{e}^{j\chi}) \cdot \boldsymbol{e}^{j\psi} = \cos(\psi - \phi - \chi)$$
$$= \cos(\psi - \chi - \phi) = \boldsymbol{e}^{j\phi} \cdot (\boldsymbol{e}^{j\psi}\,\boldsymbol{e}^{-j\chi})$$

Similarly, on the basis of the outer product,

$$(\boldsymbol{e}^{j\phi}\,\boldsymbol{e}^{j\chi}) \times \boldsymbol{e}^{j\psi} = \boldsymbol{e}^{j\phi} \times (\boldsymbol{e}^{j\psi}\,\boldsymbol{e}^{-j\chi})$$

Thus in general,

$$\left.\begin{aligned} (\mathbf{A}\mathbf{C}) \cdot \mathbf{B} &= \mathbf{A} \cdot (\mathbf{B}\bar{\mathbf{C}}) \\ (\mathbf{A}\mathbf{C}) \times \mathbf{B} &= \mathbf{A} \times (\mathbf{B}\bar{\mathbf{C}}) \end{aligned}\right\} \tag{6}$$

That is, in an inner or outer product, a directed quantity in one of the factors is equivalent to its conjugate in the other.

In particular, with $\boldsymbol{C}=\boldsymbol{j}$

$$\left.\begin{aligned}(\boldsymbol{j}\boldsymbol{A})\cdot\boldsymbol{B}&=-\boldsymbol{A}\cdot(\boldsymbol{j}\boldsymbol{B})\\(\boldsymbol{j}\boldsymbol{A})\times\boldsymbol{B}&=-\boldsymbol{A}\times(\boldsymbol{j}\boldsymbol{B})\end{aligned}\right\}\qquad(7)$$

Since the factor $\boldsymbol{i}$ may be freely inserted or cancelled in any formal product, an inner or outer product can be made a triple product by introducing the factor $\boldsymbol{i}$. Then, it follows that

$$\left.\begin{aligned}\boldsymbol{A}\cdot\boldsymbol{B}&=(\boldsymbol{i}\boldsymbol{A})\cdot\boldsymbol{B}=\boldsymbol{i}\cdot(\bar{\boldsymbol{A}}\boldsymbol{B})=(\boldsymbol{A}\bar{\boldsymbol{B}})\cdot\boldsymbol{i}\\\boldsymbol{A}\times\boldsymbol{B}&=(\boldsymbol{i}\boldsymbol{A})\times\boldsymbol{B}=\boldsymbol{i}\times(\bar{\boldsymbol{A}}\boldsymbol{B})=(\boldsymbol{A}\bar{\boldsymbol{B}})\times\boldsymbol{i}\end{aligned}\right\}\qquad(8)$$

In addition to these relations it follows directly from the definitions that

$$\begin{aligned}\boldsymbol{A}\cdot\boldsymbol{B}&=\boldsymbol{A}\times(\boldsymbol{j}\boldsymbol{B})=(\boldsymbol{A}\bar{\boldsymbol{B}})\times\boldsymbol{j}\\&=-(\boldsymbol{j}\boldsymbol{A})\times\boldsymbol{B}=-\boldsymbol{j}\cdot(\bar{\boldsymbol{A}}\boldsymbol{B})\qquad(9)\end{aligned}$$

$$\begin{aligned}\boldsymbol{A}\times\boldsymbol{B}&=(\boldsymbol{j}\boldsymbol{A})\cdot\boldsymbol{B}=\boldsymbol{j}\cdot(\bar{\boldsymbol{A}}\boldsymbol{B})\\&=-\boldsymbol{A}\cdot(\boldsymbol{j}\boldsymbol{B})=-(\boldsymbol{A}\bar{\boldsymbol{B}})\cdot\boldsymbol{j}\qquad(10)\end{aligned}$$

It must be remarked that for any conjugate quantities $\boldsymbol{D}$ and $\bar{\boldsymbol{D}}$,

$$\begin{aligned}\boldsymbol{D}\times\boldsymbol{j}&=\bar{\boldsymbol{D}}\times\boldsymbol{j}\\\boldsymbol{D}\cdot\boldsymbol{j}&=-\bar{\boldsymbol{D}}\cdot\boldsymbol{j}\\\boldsymbol{D}\times\boldsymbol{i}&=-\bar{\boldsymbol{D}}\times\boldsymbol{i}\\\boldsymbol{D}\cdot\boldsymbol{i}&=\bar{\boldsymbol{D}}\cdot\boldsymbol{i}\end{aligned}$$

Some Applications to Mechanical Problems

I. Time-rate of a directed quantity.

In general, both the magnitude and direction may be functions of time. Let

$$\boldsymbol{A}=A\,\mathbf{a}=A\,e^{j\phi}$$

where

$$A=A(t)\qquad\phi=\phi(t)$$

the total time-rate of $\boldsymbol{A}$, a new directed quantity

$$\boldsymbol{V}=\dot{\boldsymbol{A}}=\dot{A}\,e^{j\phi}+\boldsymbol{j}\,\dot{\phi}\,A\,e^{j\phi}$$

Designating the time-rate of the rotational angle ϕ by ω which is an angular velocity, variable or constant,

$$\dot{\boldsymbol{A}}=\dot{A}\,\mathbf{a}+\omega\boldsymbol{j}\boldsymbol{A}\qquad(11)$$

The two terms are the partial time-rates:

$\dot{A}\,\mathbf{a}$ is the component of the total time-rate in the instantaneous direction of $\boldsymbol{A}$. This component contributes to the change of the magnitude only, as if the direction were constant.

$\omega A\boldsymbol{j}\mathbf{a}$ is the component of the total time-rate in the direction normal to the instantaneous direction of $\boldsymbol{A}$. This component contributes to the change of the direction only, as if the magnitude were constant.

Let

$$\boldsymbol{V}=V\,e^{j(\phi+\delta)}$$

Selecting a new set of fixed reference directions $\boldsymbol{i}'$ and $\boldsymbol{j}'$ with which the directions $\mathbf{a}$ and $\boldsymbol{j}\,\mathbf{a}$ coincide instantaneously,

$$\boldsymbol{i}'=\mathbf{a}\qquad\boldsymbol{j}'=\boldsymbol{j}\,\mathbf{a}$$

$$\boldsymbol{V}=\dot{A}\,\boldsymbol{i}'+\omega A\,\boldsymbol{j}'$$

Therefore, $$V=+\sqrt{\dot{A}^2+\omega^2A^2}$$

$$\tan\delta=\frac{\omega A}{\dot{A}}$$

It must be remarked that the quantities $\dot{A}$ and ωA are necessarily of the same physical nature. Both operations $1/dt$ and ω introduce factors of the nature of angular velocity, *i.e.*, reciprocal of time $[t^{-1}]$. These relations are represented by their geometric image on the diagram (Fig. 1).

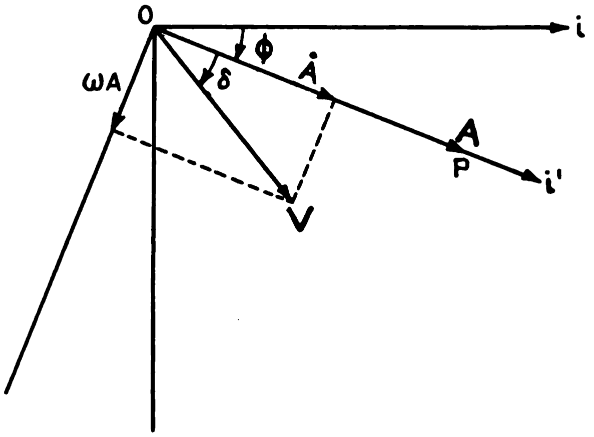

Fig. 1. Typical Vector Diagram

There is nothing about a directed quantity that requires it to be localized at any point whatever. The magnitude and direction together are sufficient to specify a directed quantity completely. The localization at the origin O is merely a matter of convenience in constructing a geometric image. The actual point P of the diagram has no physical significance even when the origin has any, except if the directed quantity is a *vector*, *i.e.*, a directed line. If A_o is the chosen basic amount of quantity A,

$$n=\frac{A}{A_o}$$

is the percentage. If L_o is a chosen basic amount of length,

$$OP=n\,L_o$$

The quantity $$s=\frac{1}{L_o}$$

is the *scale* of A, a quantity of the physical nature of curvature $[l^{-1}]$.

II. A point traveling in a circular path.

The position of a point M with respect to any fixed point O is a directed quantity, a vector, of the linear magnitude $O\,M$ and at a certain direction:

$$\boldsymbol{r}=r\,e^{j\phi}$$

If r remains constant and ϕ is a function of time, point M travels in a circular path, and line $O\,M$ rotates about O with an angular velocity

$$\omega = \dot{\phi}$$

variable or constant.

The first time-rate of r is the velocity of M:

$$v = \dot{r} = \omega\, j\, r$$

The second time-rate of r is the first time-rate of v; *i.e.*, the acceleration of M:

$$\begin{aligned} w = \dot{v} &= \dot{\omega}\, j\, r + \omega\, j\, v \\ &= \dot{\omega}\, j\, r - \omega^2 r \end{aligned}$$

The first term is the tangential component of the acceleration, in the direction normal to the instantaneous direction of r, *i.e.*, in the direction of v, and contributes to the change of the magnitude of the velocity only, without affecting the direction. The second term is the radial component of the acceleration, in the direction normal to the instantaneous direction of v, *i.e.*, opposite to r, and contributes to the change of the direction of the velocity only, without affecting the magnitude.

III. Motion of a particle in a plane space that rotates about an axis fixed in the earth space.

Let

- t be the time variable.
- O the common point of the two spaces, the center of rotation.
- i, j the reference directions fixed in the earth space in the plane of the motion.
- i', j' the reference directions fixed in the rotating space. Then, relatively to the earth space,

  $$i' = i\, e^{j\phi}$$

  where $\phi = \phi(t)$.
- $\omega = \dot{\phi}$ the variable angular velocity of the rotating space relative to the earth space.
- M the point at which the particle is instantaneously located.

Given the motion of the particle relative to the rotating space:

$r' = r'(t)$ the variable position.

$v' = v'(t) = \dot{r}'$ the variable velocity.

$w' = w'(t) = \dot{v}'$ the variable acceleration.

To establish the equation of motion of the particle in the earth space, the common practice is to write the equation of a fictitious equilibrium with the so-called "inertia forces" included as completing the equilibrium. The same results can be obtained in a direct way by writing the true equation of motion in the form

$$R = m\, w$$

where R is the resultant force, m is the mass of the particle and w is the acceleration in the earth space. It is only necessary to express w in terms of the given quantities r', v', and w'.

The direction i, fixed in the earth space may be so selected that i' instantaneously coincides with it. Then,

$$r = r'$$

instantaneously. The velocity of M in the earth space is made up of two parts: one is the time rate of r', $\dot{r}'$, in the rotating space, the other is the time-rate of r' due to the rotation of the space. Thus,

$$\begin{aligned} v &= \dot{r}' + \omega\, j\, r' \\ &= v' + v'' \end{aligned}$$

Similarly, the acceleration in the earth space

$$\begin{aligned} w &= \dot{v}' + \omega\, j\, v' + \dot{v}'' + \omega\, j\, v'' \\ &= w' + \omega\, j\, v' + \dot{\omega}\, j\, r' + \omega\, j\, \dot{r}' - \omega^2 r' \\ &= w' + \dot{\omega}\, j\, r' + 2\,\omega\, j\, v' - \omega^2 r' \qquad (12) \end{aligned}$$

This formula has a wide application. The general form in three-directional space is given by Equation (112) of Prof. Slate's "Fundamental Equations of Dynamics." The method of selecting a fixed coördinate system with which the moving coördinate system coincides instantaneously is due to Prof. Slate.

The Application of Oxygen and Hydrogen to Industrial Operations

PART VIII: ELECTROLENE

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IN last month's installment of this serial, consideration was given to the economics of hydrogen procurement by various commercial processes. In no one process has been found a combination of all desirable features, both engineering and economic. Such a combination would include the following:

(1). Maximum safety in operation.
(2). Low investment cost.
(3). Simplicity of operation (being as nearly automatic as possible).
(4). Efficient over a wide range of output within the machine's capacity.
(5). Capable of being economically built and operated for small loads.
(6). Small floor space.
(7). Low cost of operation.
(8). Dependability for continuous service.
(9). Minimum amount of auxiliary equipment needed.
(10). Minimum quantity of raw material required.
(11). Low maintenance.
(12). Dependability of composition of gas.

With the foregoing features as a guide, a new process has been developed and the product, Electrolene, is a gas capable of replacing industrial hydrogen in many applications. The composition of Electrolene, and consequently its characteristics, can be varied over a wide range by a suitable choice of the raw gas to be used and by controlling the production process. For example, the composition of Electrolene can be adjusted to the desired characteristic of specific gravity, specific heat, thermal conductivity, inflammability, air-gas ratio, flame temperature, rate of flame travel, B.t.u. content, and carburizing, decarburizing, or neutral to carbon with respect to metallurgical operations on steel.

It is generally known that hydrocarbons heated out of contact with air will break down, forming carbon and free hydrogen. This principle has been utilized in the new process which involves the complete or the partial thermal decomposition of hydrocarbons with or without steam to produce mixtures having carbon monoxide, hydrogen, and carbon dioxide as the main constituents.

The relative quantities of these gases in the mixture depend upon:

(1). The hydrocarbon being treated.
(2). The temperature to which it is heated.
(3). The amount of steam used.

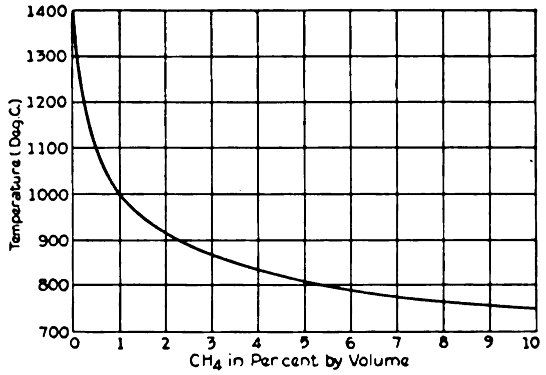

Fig. 31. Per Cent by Volume of CH_4 in Equilibrium with Hydrogen and Carbon in the System $CH_4 = C + 2\,H_2$

The hydrocarbon used as raw material may be butane, propane, ethane, city gas in which methane is the principal hydrocarbon, or a great variety of other gases.

The choice of the raw gas to be used will depend upon:

(1). Its availability.
(2). The use to which the Electrolene is to be put.
(3). Its effect upon the final cost of the Electrolene.

From the viewpoint of availability and final cost, there are four gases which are most attractive as raw material for the production of Electrolene, *viz.*, city gas, natural gas, butane, and propane.

City gas may be coke-oven gas or carburetted water gas, and from the viewpoint of availability is the ideal raw material. Natural gas is likewise readily available in many sections of the country at low cost. Butane and propane are available in tanks, but unless used in appreciable quantity are more expensive than the

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The following table facilitates the location of material hitherto published in this serial:

Part	*Issue*	*Figs.*	*Tables*
Part I	Nov. 1927, p. 544	1 to 9	I to V
Part II	Dec. 1927, p. 590	10 to 16	VI
Part III	Apr. 1928, p. 197	17 to 25	VII to IX
Part IV	May 1928, p. 279	26	X
Part V	July 1928, p. 385	27 to 29	——
Part VI	Sept. 1928, p. 493	30	XI
Part VII	Mar. 1930, p. 199	——	XII and

other two. All four gases, however, will play an important part in the industrial production of Electrolene, and there may be other hydrocarbons which because of future economic changes may take the lead.

The temperature at which these hydrocarbons are treated will be governed by the use for which the Electrolene is intended. This results from the fact that in the production of Electrolene an equilibrium is established for carbon, methane, and hydrogen according to the curve in Fig. 31. If the Electrolene is subjected during its use to higher temperature than that used in its production, more carbon will drop out. Obviously, therefore, where its use is for electric furnace atmospheres, the Electrolene must be produced at a temperature governed by the temperature in the electric furnace and the functions which the atmosphere is to perform. On the other hand, Electrolene that is suitable for cutting and other flame operations need not be produced at any definite temperature.

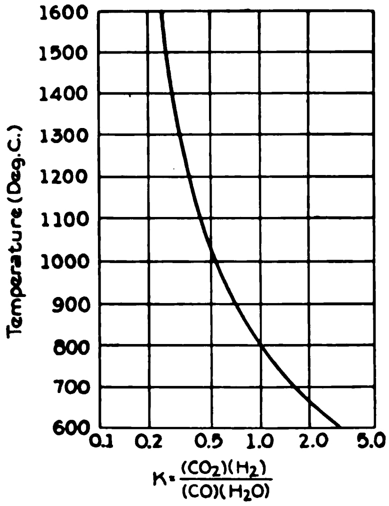


Fig. 32. Relation of Temperature to the Conversion of CO to CO_2 According to the Reaction $CO + H_2O = CO_2 + H_2$

The amount of steam used will be determined by the amount of carbon in the raw gas being treated, the operating temperature, and the relative amounts of CO and CO_2 desired. If butane is used, greater quantities of steam will be required to keep the electrolene producer free from carbon than is the case if coke-oven gas is the raw material. This results from butane (C_4H_{10}) dropping out more carbon than does methane (CH_4) on dissociation. The latter is the chief constituent of natural gas and is the hydrocarbon which when heated with steam gives the highest relative percentage of hydrogen in Electrolene.

The reaction $CH_4 + CO_2 = 2CO + 2H_2$ may be taken advantage of where Electrolene is used as the atmosphere in furnaces that operate at high temperatures. The relative amounts of CH_4 and CO_2 in the Electrolene is determined by the temperature in the producer and the quantity of steam used. Control of these factors permits either the operation of the producer at lower temperatures, or an increased output which at times may be desirable.

There may be other instances where it is desired to reduce the CO content of the Electrolene, and at the same time obtain complete dissociation of the hydrocarbons. This may be done by the intermittent use of steam, which means intermittent production; it may be accomplished by substituting for steam a manual cleaning period for carbon removal; or a second Electrolene producer may be operated in series with the first for the purpose of converting the CO to CO_2 with steam, as indicated in Fig. 32.

The subsequent removal of CO_2 by one of many well-known methods results in Electrolene which, as this reaction is carried further, approaches pure hydrogen.

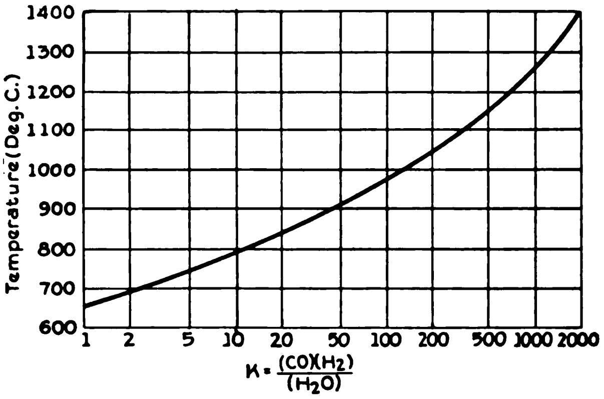


Fig. 33. Relation of Temperature to the Normal Reaction in the Electrolene Producer: $C + H_2O = CO + H_2$

In Fig. 33 are shown the equilibrium conditions for steam, carbon, and gaseous products based on the normal reaction which occurs in the Electrolene producer between the carbon from hydrocarbon dissociation and the steam. The correct quantity of the steam is maintained by thermostatic control, actuated by the saturation temperature of the gas and steam mixture delivered to the producer.

In every case an appreciable increase in volume of raw gas supplied appears as Electrolene. In the case of complete dissociation of coke-oven gas with steam in stoichiometrical proportions, one cubic foot of raw gas becomes approximately two cubic feet of Electrolene, having an approximate analysis of 72 per cent hydrogen, 23 per cent CO, and 5 per cent of "inerts." From butane a volume increase of 13 times is secured, the resulting Electrolene analyzing approximately 69 per cent H_2 and 31 per cent CO. With methane, the volume increase is four times, and the Electrolene analyzes about 75 per cent H_2 and about 25 per cent CO.

This volume increase naturally reduces the cost of the Electrolene per unit volume, but does of course increase its cost per B.t.u. The fact that the Electrolene has a smaller B.t.u. content than the original gas is not a factor, however, because its function is not that of a fuel gas, and for the purposes for which it is produced its form value is of greater worth than that of the original gas.

The features of the ideal gas producing process have been outlined and a study of the Electrolene process with such a pattern in mind shows that it fills an industrial need.

Safety in Operation

At no time during the process are by-products produced which in their subsequent mixing with Electrolene can form an explosive mixture. It is the safest method of producing a gas of such high form value, and the usual procedure in handling inflammable gases will afford ample safety in operating the producer.

Investment Cost

For a given amount of money invested in Electrolene equipment, more capacity can be obtained than from any other apparatus capable of producing a competitive gas. By "competitive" is meant a gas having the range of industrial utility possessed by Electrolene.

Simplicity of Operation

The Electrolene producer need not be operated in conjunction with a gas holder because in most instances it can be located in series with the raw-gas supply and at the point of use. This arrangement permits drawing gas as needed. The electric heat supply is automatically controlled to maintain any desired temperature, and the steam supply is also automatically regulated for any rate of output, so that one valve controlling the Electrolene flow from the producer is the only part of the equipment requiring manual attention. If the Electrolene load is constant, the producer can be set for such requirements and no further attention is needed outside of a casual inspection periodically. If the load demand varies, gas may be drawn as and when needed, provided the maximum demand is kept within the producing capacity of the unit.

Efficiency When Operating at Less Than Full Load

The Electrolene producer is no exception to the rule that the efficiency of a machine is less at partial load than at full load. In the case of the producer, the operation is conducted with a radiation loss that is more or less constant and the heat lost per unit quantity of gas is more at reduced outputs. For this reason, multiple units are preferable to large units where operation at less than full load is to be the practice.

Floor Space

The Electrolene producer need not necessarily be installed in a building, but the space required is so small that it becomes almost a negligible factor. A 1000-cu. ft. per hr. unit has outside dimensions of 7 ft. diameter and 14 ft. high, with a probability of future reductions in space requirements. None of the hydrogen-producing processes can compare with it in the small floor space required.

Low Cost of Operation

The final cost of Electrolene will depend upon the raw gas used and the cost of power. If coke-oven gas is available at a price of $0.60 per M cu. ft., and power at $0.01 per kw-hr., the base charges for the Electrolene produced will be in the vicinity of $0.75 per M cu. ft.

Dependability

The production of Electrolene depending as it does upon a supply of power, steam, and raw gas supply, will be as reliable in its continuity as these three services.

Auxiliary Equipment Needed

While the auxiliary equipment needed will depend upon the local conditions at the point of use, the money value of such equipment will be relatively small. Such equipment includes meters, dryers, a small pump, and control equipment.

Raw Material

The raw materials, *i.e.*, gas, steam, and power, are conveyed to the producer without manual labor. They are readily available both geographically and seasonally, and their cost has been steadily declining. There is no probability that a shortage of these materials will take place, and this assures an adequate supply of raw materials for Electrolene producers.

TABLE XIV

INDUSTRIAL GASES

Gas	CONSTITUENTS OF THE GAS (PER CENT BY VOLUME)								
	CH_4	C_2H_6	C_2H_4	CO_2	CO	H_2	O_2	N_2	C_6H_6
Natural Gas	96			0.8				3.2	
Natural Gas	80	19						1.0	
Coal Gas	40		4.0	0.5	6.0	46	0.5	3.0	
Coke Oven Gas	23		3	3	9	57		5	
Coke Oven Gas	33		6	3	6	48		4	
Carburetted Water Gas	20		12	0.22	26	36.5	0.03	3.25	2
Water Gas	2			4	45	45	0.5	2	H_2O 1.5
Producer Gas	1.3			4.0	28.6	12.3	0.3	53.5	
Electrolene	Subject to Control								

Maintenance

The maintenance is small and about the same order that would prevail in connection with an electric furnace of the same size and temperature range. A long life of metal parts and heating units is assured, because of the protecting atmosphere afforded by the Electrolene at the high temperatures.

The Electrolene producer shown as the cover illustration of this issue of the Review has a capacity of 1000 cu. ft. per hr.

Energy Requirements

The energy supplied to the Electrolene producer in the form of heat has the following functions:

Sensible Heat

(1). Increasing the temperature of the raw gas and steam to the reaction temperature.
(2). Supplying the radiation losses.

Latent Heat

(1). Heat energy required for dissociation of hydrocarbons.
(2). Heat energy required for dissociation of steam.

The heat required to raise the temperature of the gas and steam depends upon:

(*a*). The operating temperature.
(*b*). The nature of the raw gas used.

Knowing the constituents of the raw gas and their specific heats, it is a simple matter to determine the effective heat input needed to increase these components to any given temperature.

The radiation loss in B.t.u. per unit quantity of gas produced is a function (within limits) of apparatus design. As the efficiency of the apparatus is increased the radiation loss per unit volume of output decreases, so that in the ideal unit utilizing heat recuperation the heat input approaches the quantity needed for the endothermic reaction involved. Investigation indicates that this is an exceptionally small quantity compared, for example, to the energy required for the electrolysis of water.

Selecting a typical city gas, such as coke-oven gas, we find that methane is the hydrocarbon which predominates. Where methane is heated out of contact with air the following reaction occurs:

$$CH_4 = C + 2H_2 \dots\dots\dots\dots \text{ 38,280 B.t.u.}$$

The liberated carbon reacts with steam

$$C + H_2O = CO + H_2 \dots\dots \text{ 71,200 B.t.u.}$$

These equations might be written

$$CH_4 + H_2O = CO + 3H_2 \dots \text{ 109,480 B.t.u.}$$

The average latent heat involved in the dissociation of methane and the reaction of the liberated carbon with steam according to this equation in coke-oven gas will not exceed 82,000 B.t.u. per M cu. ft. of coke-oven gas treated, or approximately 28 kw.

The average sensible heat required for operating at 1000 deg. C. and assuming no recuperation would be 60,000 B.t.u. per M cu. ft. of gas treated, or approximately 17.5 kw.

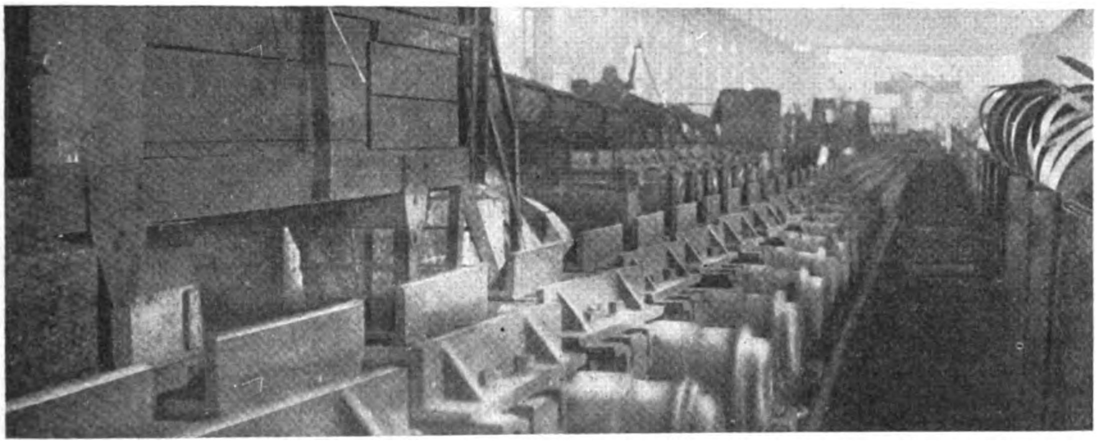
The total sensible and latent heat input per thousand cubic feet of coke-oven gas treated approximates 45 kw. This energy input, neglecting radiation losses, results in the production of approximately 2000 cu. ft. of Electrolene, or the connected load (neglecting radiation loss and assuming no heat recuperation) approximates 22.5 kw. when producing at the rate of 1000 cu. ft. of Electrolene per hour.

This gives a theoretical figure of approximately 44 cu. ft. of Electrolene per kw-hr. as compared to 10.6 cu. ft. of hydrogen per kw-hr. when produced by the electrolysis of water.

In practice, Electrolene producers developed to date deliver 24 cu. ft. of Electrolene per kw-hr. and electrolytic cells will produce 8 cu. ft. of hydrogen per kw-hr. at about 75 per cent energy efficiency.

Future installments of this serial will consider the industrial uses for Electrolene.

Individual Roller Drive on a Runout Table



One hundred and seventy-eight motors operating from a motor-generator set furnish the means of keeping things moving on this runout Speed control is obtained by varying the frequency

Modernization of the Chicago & Joliet Electric Railway

Reasons for Making the Change—Distribution Equipment Before and After Replacement—New Equipment Includes Synchronous Converters and Mercury-arc Rectifiers—Savings Obtained

By A. W. BAUMGARTEN

Division Engineer, Chicago & Joliet Electric Railway Company

THE Chicago & Joliet Electric Railway Company, in common with other similar properties in all parts of the United States, has in recent years experienced an increase in operating expense and, because of automobile competition, a considerable decrease in the number of passengers carried.

This company provides electric railway and bus service in Joliet (Ill.) a city of about 50,000 population, and as indicated in Fig. 1 it also operates an interurban line between that city and Summit, a suburb of Chicago. Hourly service is maintained over the main line and local service at each end.

An interesting study of the conditions on this road is shown in Fig. 2. The most significant development during the 25-yr. period indicated has been the rapid increase in competition from privately owned automobiles, and this has been particularly rapid during the last ten years. Correspondingly, there has been a definite trend downward in both the number of passengers carried and the revenue for the electric railway. Despite this fact the management has continued to provide a normal service as indicated by the number of car-miles operated.

In an effort to compensate for this loss in revenue a comprehensive study was made and a definite plan worked out to reduce the cost of providing the service and at the same time to make it more attractive to the riding public. This program included a complete rehabilitation of the direct-current distribution system, including conversion equipment, and a replacement of the rolling stock on the interurban line by modern light-weight one-man cars, providing unusual comfort and safety for the passengers.

Power Supply

Some 30 yr. ago, when this road was built, power was supplied from three substations, located at Joliet, Lemont, and Summit. The initial equipment included induction motor-generator sets, backed up by storage batteries to reduce the power demands on the hydroelectric system which at that time was the source of supply. About 1912, the capacity of the substations at Joliet and Summit was increased by the addition of synchronous motor-generator sets; and in 1914, due to changes in operating conditions and the larger capacity of the alternating-current power supply available at that time, the storage batteries were discarded.

Prior to undertaking the improvement in the direct-current power supply, the substation equipment included the following units:

Joliet Substation:
One 500-kw. induction motor-generator set.
Two 250-kw. induction motor-generator sets.
One 500-kw. synchronous motor-generator set.

Lemont Substation:
Two 250-kw. induction motor-generator sets.

Summit Substation:
Two 250-kw. induction motor-generator sets.
One 500-kw. synchronous motor-generator set.

Alternating-current power for the Joliet station was purchased from the Public Service Company of Northern Illinois at the Joliet substation of that company and transmitted over the Railway Company's 2300-volt line for a distance of about 1½ miles; while

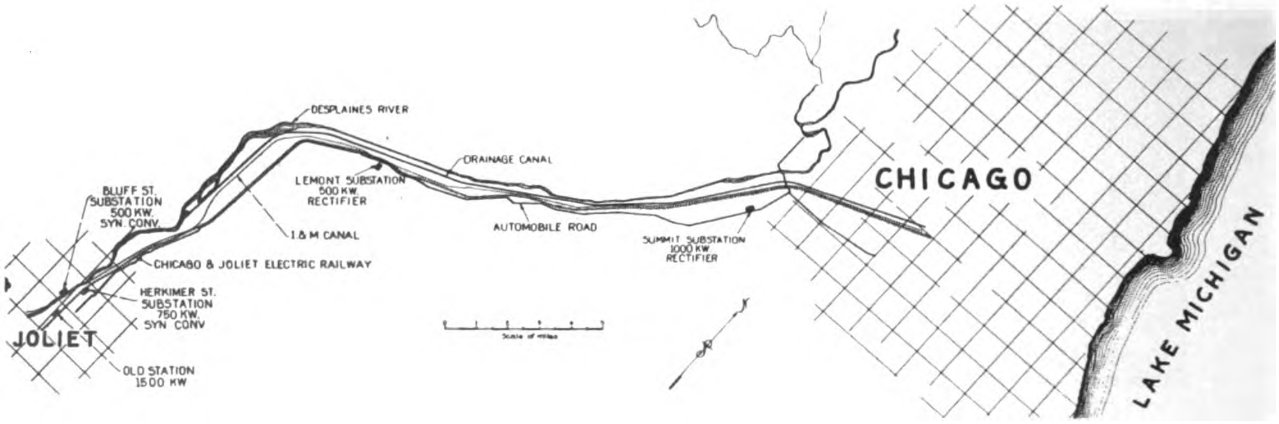

DESPLAINES RIVER
DRAINAGE CANAL
BLUFF ST. SUBSTATION 500 KW. SYN. CONV.
LEMONT SUBSTATION 500 KW. RECTIFIER
I & M CANAL
AUTOMOBILE ROAD
SUMMIT SUBSTATION 1000 KW. RECTIFIER
CHICAGO
CHICAGO & JOLIET ELECTRIC RAILWAY
HERKIMER ST. SUBSTATION 750 KW. SYN. CONV.
Scale of miles
JOLIET
OLD STATION 1500 KW
LAKE MICHIGAN

Fig. 1. Map of the Chicago & Joliet Electric Railway

33,000-volt alternating-current power for the Summit and Lemont stations was purchased from the same company at the Railway's Summit substation, Lemont being supplied over the Railway's 12½-mile 15,000-volt transmission line. A similar transmission line was maintained from Lemont to Joliet to provide for emergency conditions.

As a part of the program for rehabilitation of the direct-current distribution system, a survey and a study of existing operating equipment was made and a definite program of modernization undertaken. In the city of Joliet, the motor-generator sets were relatively inefficient; and the rebuilding of the waterway through the city, forming a part of the Lakes to Gulf waterway, made a rearrangement of feeder circuits desirable. Consequently, it was decided to replace the old station with two new stations.

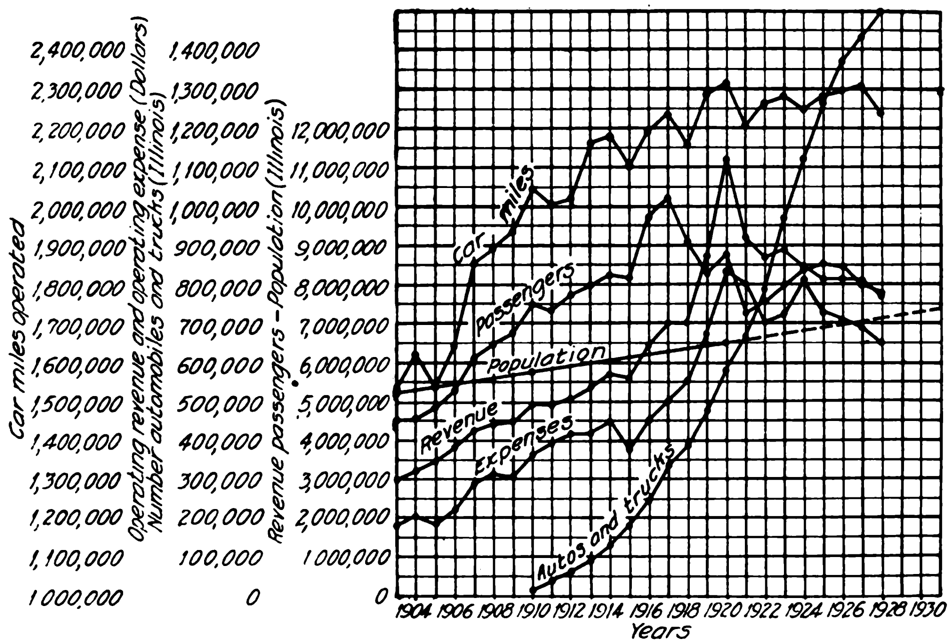


Fig. 2. Curves Showing Trends in Population, Railway Traffic, and Competing Traffic Before and After the Modernizing of the Railway Equipment

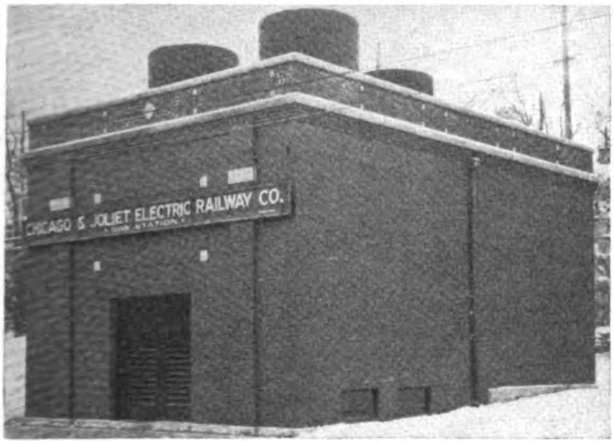


Fig. 3. The West Side Substation (Bluff St.)

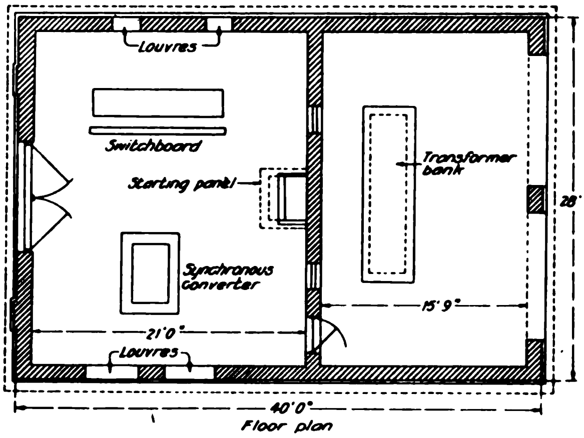


Fig. 4. Floor Plan of the West Side Substation

This work was completed about the end of 1926, and the two new stations and their equipment are:

East Side Substation (Herkimer St.):
One 750-kw. General Electric synchronous converter with full-automatic control.

West Side Substation (Bluff St.):
One 500-kw. General Electric synchronous converter with full-automatic control.

Alternating-current 12,000-volt 3-phase 60-cycle power is now purchased at these substations.

Reference is made later to the saving of copper and aluminum resulting from the relocation of the stations and the rerouting of the direct-current feeders. A further result of these changes was an improvement in the average operating voltage, which, in turn, resulted in a reduction of the direct-current distribution losses and permitted the inauguration of faster schedules.

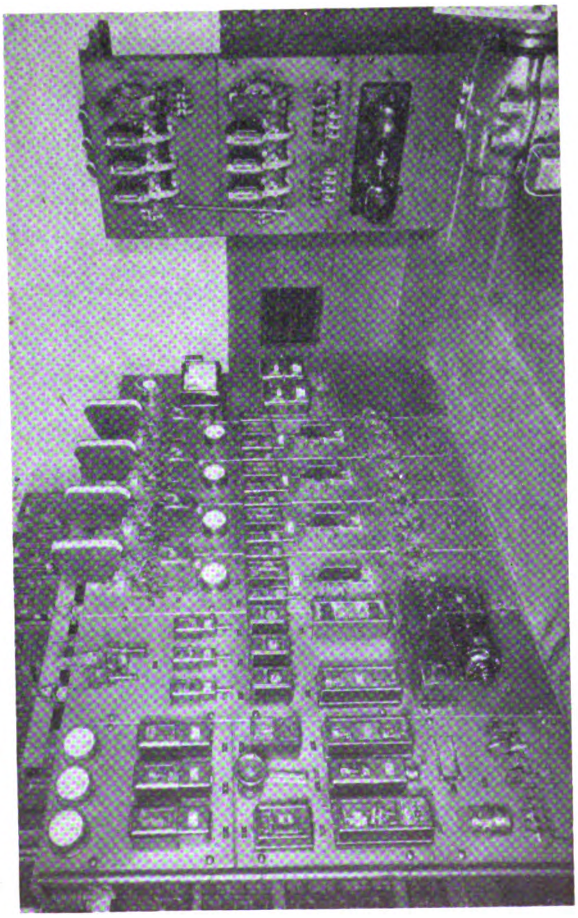


Fig. 5. The Full-automatic Synchronous Converter and Feeder Control Equipment in the West Side Substation

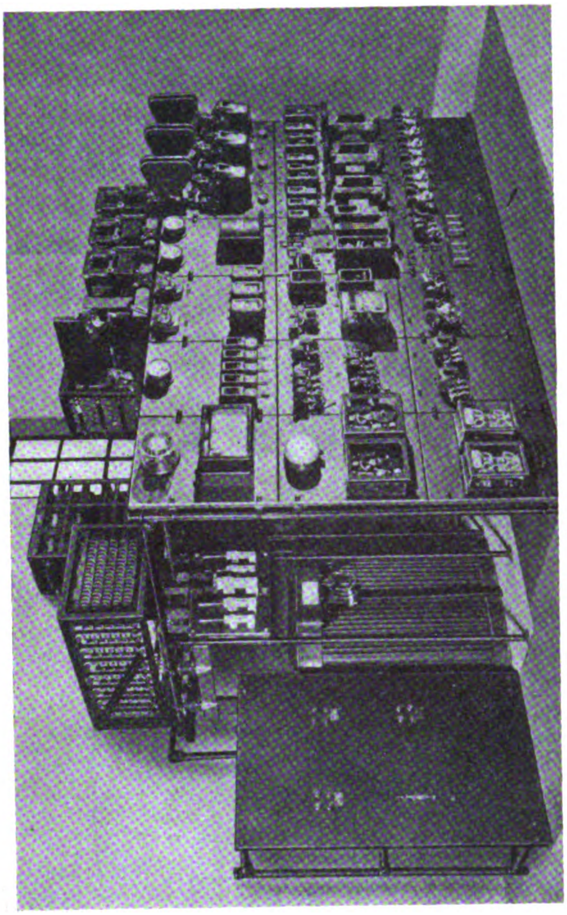


Fig. 6. The Mercury-arc Rectifier Switchboard in the Summit Substation

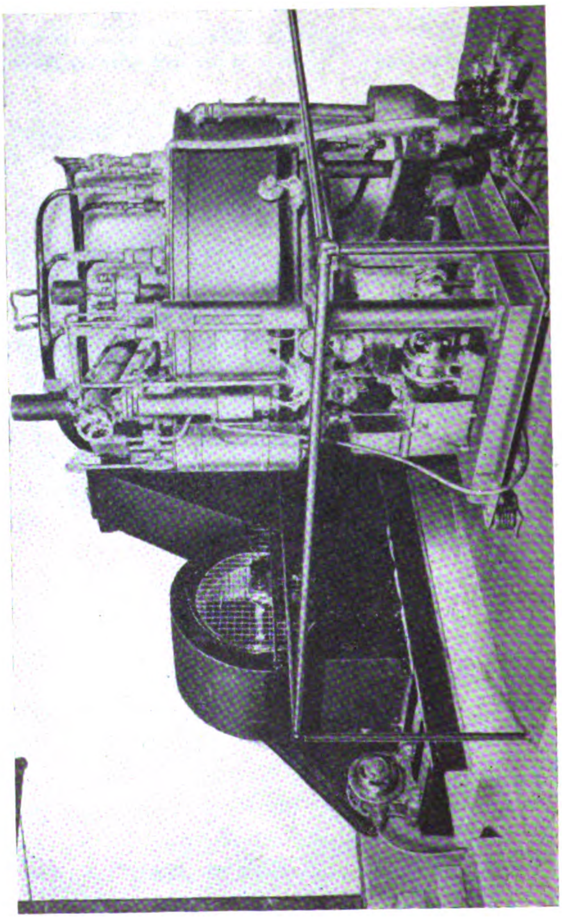


Fig. 7. The 1000-kw. 600-volt Rectifier and Blower for the Closed Cooling System in the Summit Substation

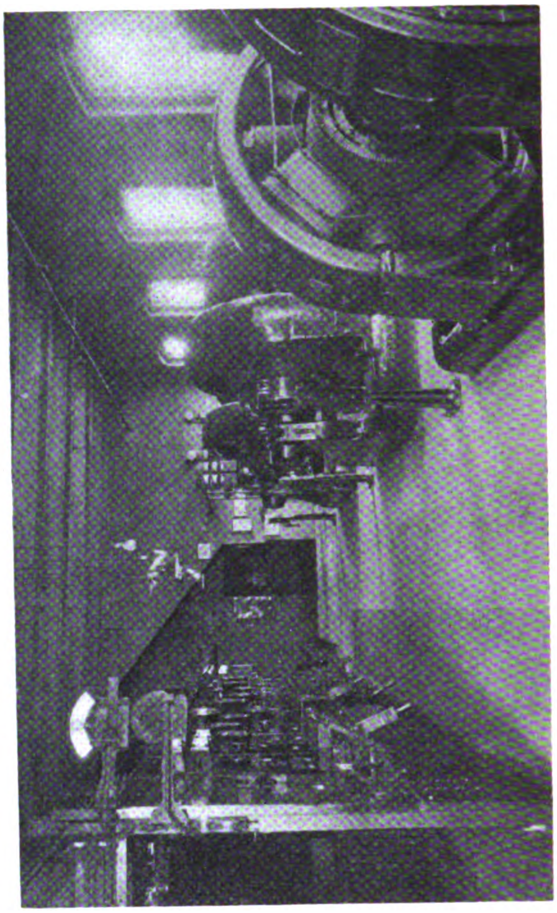


Fig. 8. The Motor-generator Sets and Switchboard in the Summit Substation, which Are Replaced by the Rectifier Equipment Shown in Figs. 6 and 7

The new substation buildings (Fig. 3 and Fig. 4) are of a modern design and incorporate some unusual features in the way of simplicity of construction and provide semi-protection for the transformers and oil switches, this being done with the view to permitting routine maintenance to be carried on with some comfort during inclement weather.

The brick, concrete, and steel construction of these buildings, while extremely simple, is also compact and provides good ventilation. The walls are without windows, but louvres are located in the sides and doors. The air inlet is at the floor line and ventilators are included in the roof construction to insure adequate air circulation. The total cost of these buildings, exclusive of land and equipment, did not exceed $8,000 each.

For the Lemont and Summit substations, mercury-arc rectifier equipment was selected with full-automatic control to secure the benefits of the higher all-day efficiency of this type of apparatus. Small floor changes permitted the installation of the new equipment in the existing stations. The new installations included:

Lemont Substation:

One 500-kw. 600-volt General Electric mercury-arc rectifier with closed cooling system.

Summit Substation:

One 1000-kw. 600-volt General Electric mercury-arc rectifier with closed cooling system.

These stations were placed in operation in August, 1928, and August, 1929, respectively. At this time the power supply for the Lemont Station was changed, the Public Service Company of Northern Illinois delivering alternating-current power at both stations, thereby permitting the salvaging of 25 miles of transmission line.

As compared with synchronous-converter equipment, the automatically-controlled mercury-arc rectifier eliminates the following:

(1). Starting and running voltage application.
(2). Polarization.
(3). Polarity checking equipment.
(4). Overspeed protection.
(5). Brush raising and lowering.
(6). Bearing temperature protection.

However, the rectifier adds other or new functions not required by the synchronous converter. These are:

(1). Tank temperature regulation and protection.
(2). Tank pressure regulation and protection.
(3). Mercury condensation pump protection.
(4). Arc starting and excitation.
(5). Auxiliary cooling system.

Other advantages in favor of the rectifier with reference to installation and maintenance may be enumerated briefly as follows:

(1). Cheaper building.
(2). Lower cost of installation.
(3). Less noise.
(4). Less danger of flashover.
(5). Easier to clean.
(6). No commutation trouble.
(7). No bearing troubles.
(8). Time of inspection less than one-half.

The disadvantages of a mercury-arc rectifier are:

(1). Maintenance of cooling system.
(2). Temperature and vacuum control.

The 500-kw. mercury-arc rectifier replaced two 250-kw. manually operated motor-generators at the Lemont station, resulting in a power saving of 13 per cent. It has also made two substation operators unnecessary and has eliminated the cost and maintenance and operation of the 25 miles of transmission line between Joliet and Summit, so that the total annual savings in operating costs resulting from the installation of the initial mercury-arc rectifier substation are as follows:

Total power saving from increased efficiency	$2,676.00
Salaries of substation operators	3,600.00
Maintenance of substation equipment	300.00
Maintenance and depreciation of transmission lines	3,000.00
Total savings	$9,576.00

The estimated annual savings resulting from the installation of the 1000-kw. unit in Summit station are as follows:

Total power saving from increased efficiency	$1,600.00
Salaries of substation operators	3,600.00
Maintenance of substation equipment	500.00
Total estimated savings	$5,700.00

Similar savings obtained from the operation of the new Joliet stations, bring the total for the system to $20,000 annually. The total cost of rehabilitation of the power supply system was approximately $185,000; but the salvage value of the copper and aluminum feeders and transmission lines reduced this to $160,000 so that the total annual saving represents about 12½ per cent on the investment. In this analysis no attempt has been made to capitalize the benefits accruing from a more efficient and reliable power supply.

To summarize: This installation demonstrates clearly the possibility of economy in railway operation by modernizing the power-supply system. This includes the advantages of high efficiency of the mercury-arc rectifier and synchronous converter, as compared with older motor-generator sets; the savings in operation by the use of automatic control; and the reduction of distribution costs because of the more satisfactory arrangement of feeders. A definite saving in power is furthermore possible by the substitution of new rolling-stock equipment. In this case ten new 42,000-lb. cars replaced a similar number of 65,000-lb. cars on the interurban system.

Cable Heating in Underground Ducts

Heat Losses Encountered—Evaluation of Various Losses—Example of Loss Calculation for a Typical Arrangement—Derivation of Expressions for Evaluation of Heat Losses

By RUSSELL D. LEVY
Electrical Engineer, Southeastern Engineering Company

VARIOUS phases of the subject of cable heating in underground ducts have been treated in the technical literature from time to time. The whole of the subject, to the writer's knowledge, has never been made available to engineers in a form suitable for rapid and simple computation of allowable cable loading. To give such a method is the purpose of this article.

Preliminary

Heat flow is accompanied by a temperature drop, the amount of which is proportional to the heat flow and to the thermal resistance of the path over which the heat flows. The problem of computing the total temperature of the hottest part of the insulation in a cable resolves itself into problems of determining the thermal resistances of the path over which the heat generated in the cable flows, on its way to the ultimate reservoir, or "sink." Parts of this path are used by the heat from the other cables in the same duct bank, so consideration must be given to all the cables in the duct bank when investigating one. For all practical purposes, the hot spot of the insulation may be considered at the same temperature as the copper core.

Cable losses originate in three places: in the copper, as a resistance loss; in the dielectric, as a dielectric hysteresis and leakage loss; and in the sheath, as a resistance loss due to sheath currents set up by induction from the core. The dielectric loss increases with temperature for commonly used insulation, and since the copper is practically the hottest part of the cable, most of the dielectric loss will be generated near the copper. The error in considering that all of the dielectric loss originates at the copper, at the copper temperature, is not large and is on the safe side. Making this assumption, the path of heat flow is as follows: The copper and the dielectric losses flow from the copper to the insulation, through the insulation, and from the insulation to the lead sheath; in the sheath, the copper and the dielectric losses are supplemented by the sheath loss and these three losses flow from the sheath to the duct air. The heat from each duct flows to the outer wall of the duct bank structure over a complex path; the total bank heat then flows through the outer wall of the duct bank structure to the outer surface of this wall, thence to the adjacent earth and finally to the "sink." The thermal resistances of some of the parts of this path are negligibly small. These resistances, (*1*) due to contact between the copper and the insulation, (*2*) due to contact between the insulation and the lead, (*3*) across the lead sheath, and (*4*) due to the contact between the outer surface of the outer wall of the duct bank structure and the adjacent earth, may all be omitted. The path is thus divided into four component resistances:

h_i, the thermal resistance of the insulation.

h_s, the thermal resistance of emissivity from the lead sheath to the duct air.

h_d, an effective thermal resistance for each duct, which when multiplied by the total bank loss gives the temperature difference between the air in the duct considered and the outer surface of the outer wall of the duct bank structure.

h_b, the thermal resistance from the outer surface of the structure to the "sink."

The method now to be outlined divides the total temperature rise of the copper over the temperature of the "sink" into these parts:

ΔT_1, the temperature rise of the copper over the duct air due to the copper and the dielectric losses; or $\Delta T_1 = (h_i + h_s)\ (q_c + q_d)$.

ΔT_2, the additional rise of the lead sheath over the duct air due to the sheath loss; or $\Delta T_2 = h_s q_s$.

ΔT_3, the rise of the duct air over the outer surface of the outer wall of the duct bank structure; or $\Delta T_3 = Q h_d$.

ΔT_4, the rise of the outer surface of the outer wall of the duct bank structure due to the total bank loss; or $\Delta T_4 = Q_m h_b$.

In the foregoing, it is found that q_c, q_s, and Q may be the average of the peak hour's losses and that Q_m may be the mean total bank loss over twenty-four hours. These averagings are made possible by the heat storage capacities of the various parts involved.

ΔT_1: The Temperature Rise of the Copper Over the Duct Air Due to Copper and the Dielectric Losses

As previously defined, $\Delta T_1 = (q_c + q_d)\ (h_i + h_s)$, where q_d is the dielectric loss in watts per foot of cable, q_c is the copper loss in watts per foot of cable as determined by the root mean square of the currents over the peak hour, and h_i and h_s are thermal resistances, both in deg. C. per watt per foot.

The value of h_i for single-conductor cables is quite simply derived.* It is

$$h_i = 0.368\,K \log_{10}\frac{d_1}{d_3}$$

where K is the thermal resistivity of the insulation in deg. C. per watt for a foot cube. Its values are given by Dushman as follows:

For rubber	$K=21$
For varnished cambric	$K=24$
For impregnated paper	$K=29$

These values may be somewhat conservative for average modern cable materials. Justification for their use lies in the fact that a large proportion of installed cable is not modern.

Simons has done a great deal of work on the determination of h_i for multiconductor cables. Using Mie's approximate formula with a graphical correction, he arrives at results for three-conductor round cables which are very well expressed by the following empirical relation:

$$h_i = K\left[0.140\log_{10}\left(\frac{e_1+e_2}{d_3}+0.16\right)-0.010\sqrt{\frac{e_1+e_2}{d_3}}+0.111\right]$$

which holds for $e_1=e_2$ only.

An approximate derivation for three-conductor sector cables (given in Appendix A) shows

$$h_i = 0.368\,K\left(\frac{d_2}{d_2-\frac{e_2}{2}}\right)\log_{10}\frac{d_1}{d_2-2e_2}$$

The value of h_s is dependent merely upon the area of the lead sheath and the emissivity constant of lead to free air. Thus,

$$h_s = \frac{k}{\pi D}$$

where k is the rise in deg. C. of a strip of lead one inch wide by one foot long when one side of it is exposed to free air and dissipates one watt. Dushman gives values of k from 11.5 to 16 for dull to bright lead respectively. As a fair value, 15 has been used.

The quantities h_i and h_s have been combined and plotted as H_t in the charts given in Fig. 1 for various cables. Fig. 2 is a copper loss chart. Data for computing the dielectric losses are given in Fig. 3.

ΔT_2: The Additional Temperature Rise of the Lead Sheath Over the Duct Air Due to Sheath Losses

The second part of the temperature rise is $\Delta T_2 = q_s h_s$, where q_s is the sheath loss in watts per foot of cable due to the root mean square of the core currents over the peak hour, and where h_s is the thermal resistance as before.

In cables where the vector sum of the core currents is zero, the sheath losses are negligible. Three-conductor three-phase cables, therefore, need not be investigated. Single-conductor cables in three-phase groups, however, may have sizable sheath losses. Even for the simple case of solidly bonded sheaths, the sheath losses are difficult to determine, except for symmetrical spacing, where the spacing is large compared to the cable diameter. For the case of symmetrically spaced cables with small center distances (this is commonly met with where three single-conductor cables are pulled into one duct) the proximity effect makes exact computation by simple mathematical analysis impossible. When the cables are arranged unsymmetrically, *i.e.*, in "L" or flat, and the spacing is large enough to neglect proximity effect a further difficulty arises. This difficulty is that a voltage exists between the points of bonding, so that if the sheaths are grounded at more than one point, a current will flow through an earth path, the impedance of which is unknown. The analysis which led to the curves in Fig. 4, showing the lead sheath losses, is given in Appendix B. This analysis accounts but roughly for proximity effect, and considers the case of solid bonding with the sheaths grounded at only one place.

Where special insulated splices are used, the sheath losses may be made very nearly zero, or they may be reduced by the use of insulated spliced and bonding reactances or transformers, or cross-bonding connections. These expedients result in increased sheath-to-ground voltages and, sometimes, consequent troubles from electrolysis. A consideration of the advantages and disadvantages of these bonding methods, is beyond the purpose of this paper.

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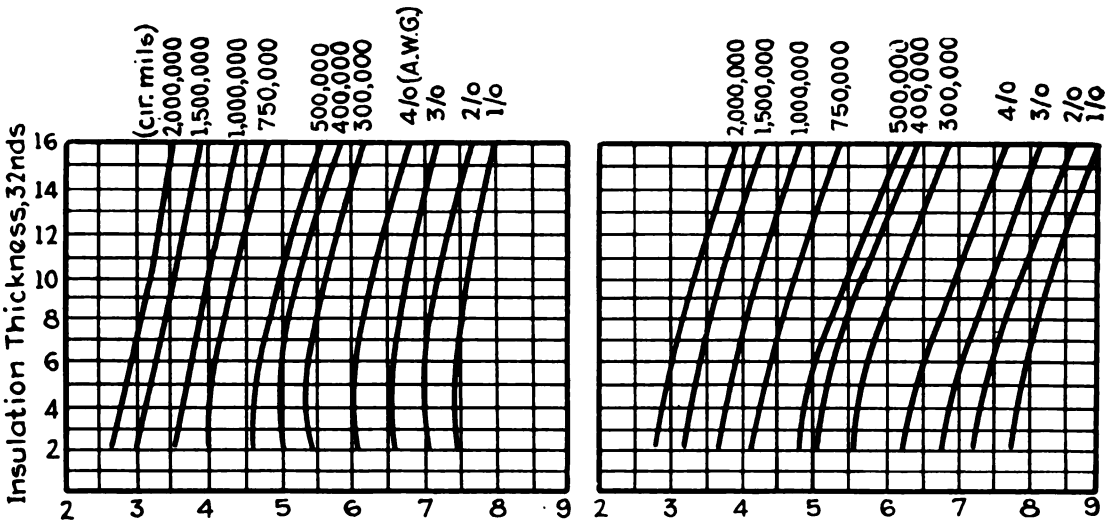
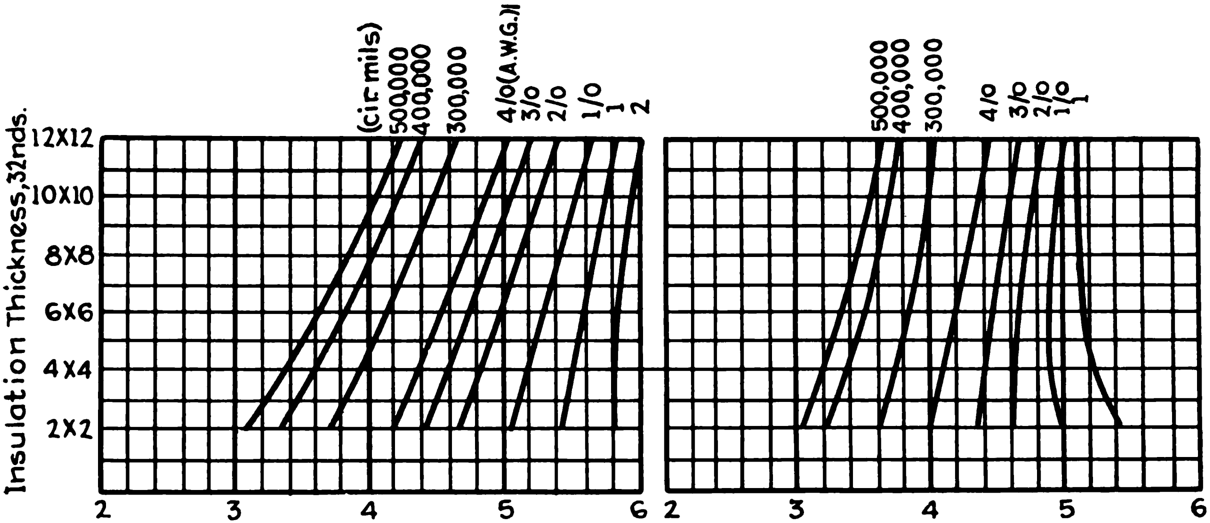
*LIST OF DEFINITIONS OF THE SYMBOLS USED IN THIS ARTICLE:

D—Outside diameter of cable over lead sheath, inches.
d_1—Inside diameter of lead sheath, inches.
d_2—Diameter of circle circumscribing conductor insulation, inches.
d_3—Diameter of conductor, inches.
d_4—Diameter over conductor insulation, inches.
e_1—Thickness of belt insulation, inches.
e_2—Thickness of conductor insulation, inches.
e_3—Thickness of lead sheath, inches.
g—Depth below surface of earth to center of duct bank, feet.
h—Height of duct bank, feet.
h_i—Thermal resistance of cable insulation in deg. C. per watt per foot of cable.
h_s—Thermal resistance of emissivity from cable sheath, deg. C. per watt per foot.
h_e—Thermal resistance, from outer surface of the outer wall of the duct bank structure to adjacent undisturbed earth, in deg. C. per watt per foot of structure.
h_d—Effective thermal resistance from duct air to outer surface of outer wall of duct bank structure in deg. C. per watt per foot of structure.
H_t—Cable heating constant in deg. C. per watt per foot of cable (h_i+h_s).
I—Copper current, amperes.
i—Sheath current, amperes.
K—Thermal resistivity of insulation, deg. C. per watt for a foot cube.
k—Thermal resistivity of emissivity, deg. C. per watt for 12 square inches.
Q—Total watts loss per foot of duct bank (average of peak hour).
Q_m—Total watts loss per foot of duct bank (averaged over 24 hours).
q_c—Copper loss in watts per foot of cable (averaged over peak hour).
q_d—Dielectric loss in watts per foot of cable.
q_s—Sheath loss in watts per foot of cable (averaged over peak hour).
R, r—Various electrical resistances as described in text.
S—Thermal resistivity of soil in deg. C. per watt for a foot cube.
T_g—Temperature of undisturbed earth at duct level, deg. C.
ΔT_1—Temperature rise of copper over duct air due to q_c and q_s, in deg. C.
ΔT_2—Temperature rise of sheath over duct air due to q_s, in deg. C.
ΔT_3—Temperature rise of duct air over outer surface of bank, deg. C.
ΔT_4—Temperature rise of outer surface of bank over adjacent undisturbed earth, deg. C.
w—Width of duct bank in feet.
X, x—Various reactances as described in text.
Y_o—Cable admittance (to neutral), for specific inductive capacity of unity, at 60 cycles.



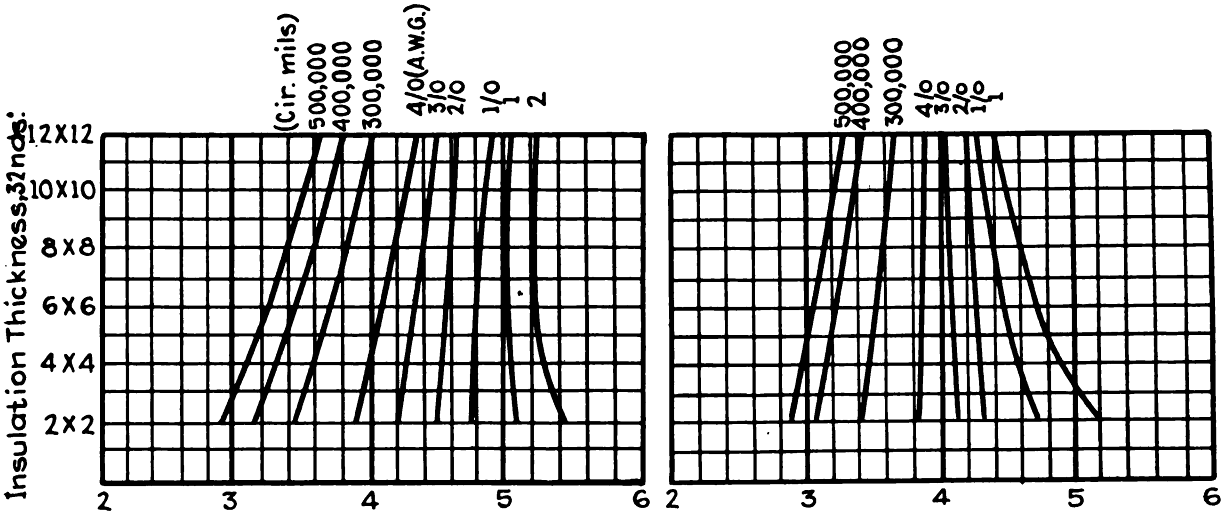
Heating Constants (H_t)
Single-conductor Leaded;
Varnished Cambric Insulated

Heating Constants (H_t)
Single-conductor Leaded;
Paper Insulated



Heating Constants (H_t)
3-conductor (Round) Leaded;
Paper Insulated

Heating Constants (H_t)
3-conductor (Sector) Leaded;
Paper Insulated



Heating Constants (H_t)
3-conductor (Round) Leaded;
Varnished Cambric Insulated

Heating Constants (H_t)
3-conductor (Sector) Leaded;
Varnished Cambric Insulated

Fig. 1. Chart of Cable Heating Constants for Various Cables

Note: When there are no sheath losses, Cable Heating Constant × (Total Cable Copper Loss + Dielectric Loss) = Temperature Rise of Copper Over Air Surrounding Sheath.

The curves shown in Fig. 4 enable one to read off ΔT_2 for various cable diameters and cable arrangements, for a core current of 100 amp. Likewise, the sheath losses shown in Fig. 5 are for a core current of 100 amp. The sheath losses and ΔT_2 vary as the square of the copper core current.

As in the case of the copper losses, the current used in computing sheath losses may be the root mean square of the currents over the peak hour.

ΔT_3: The Temperature Rise of the Duct Air Over the Outer Surface of the Outer Wall of the Duct Bank Structure

This part of the temperature rise is given as $\Delta T_3 = Qh_d$, where Q is the average of the peak hour's total duct bank losses in watts per foot of the structure, and h_d is the effective thermal resistance as previously defined. This effective resistance is called the "hole constant."

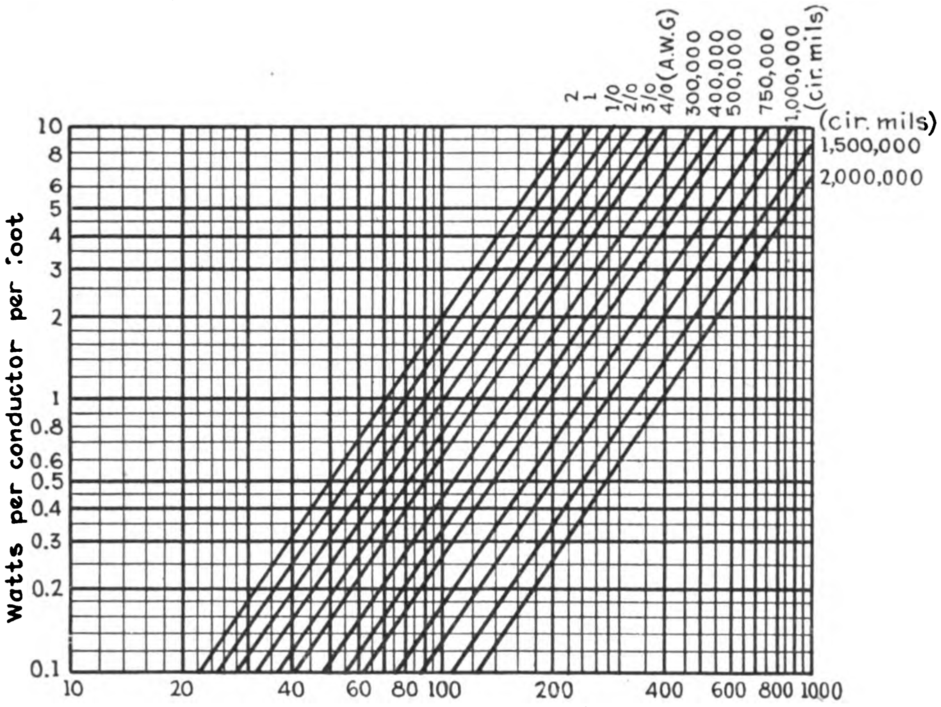


Fig. 2. Copper Loss Chart for Various Cables

Note: For conductors over 500,000 cir. mil. on a.c., multiply chart watts by $1+7\left(\frac{\text{cir. mil}}{10{,}000{,}000}\right)^2$. Use chart directly for d.c. Correction is negligible for cable sizes below 500,000 cir. mil.

Since the hole constant will vary for any duct, depending upon the losses in the other ducts of the bank, a generalization is quite out of the question. These hole constants, with the bank full and with equal losses in each of the ducts, have been determined for various duct banks, and are shown in Fig. 6. Correction curves are also shown in an accompanying graph from which it is possible to obtain the hole constants for partially filled duct banks, where the full holes have approximately equal losses. The values obtained directly from Fig. 6 may be used as long as the losses in the filled holes do not vary from the mean by more than fifteen or twenty per cent. When the losses in the filled holes are sufficiently different, it is best to use another correction factor, selected mostly by judgment. It is usually true that the proper hole constant is between the value obtained by using the equal-loss method and L times this value, where L is the ratio of the watts loss per foot in the duct under consideration to the mean watts loss per foot per filled hole in the bank. Just where to go between these values is usually pretty well defined by the losses in the surrounding ducts.

The method used in computing the thermal resistances, designated as h_d, or hole constants for full duct banks where the bank loss is equally divided among the ducts, was simply the solution of the grids such as that shown in Fig. 7 for a three by two duct bank. The values of the resistances X and Y were determined by tests on actual installations and checked by analysis of the thermal resistance of emissivity from the duct walls to duct air. As an example of the method of determination of these resistances from test, we will take the test⁽¹⁾ made on a nine by nine duct bank with 80 cables, the central duct being empty. This test gave the following results: Average temperature drop from middle nine ducts to next outer row of sixteen ducts was 0.06 deg. C. per watt loss per foot of structure; average temperature drop from middle nine ducts to the second next outer twenty-four ducts, was 0.14 deg. C. per watt loss per foot of the structure; average temperature drop from the middle nine ducts to the outer thirty-two ducts was 0.22 deg. C. per watt per foot

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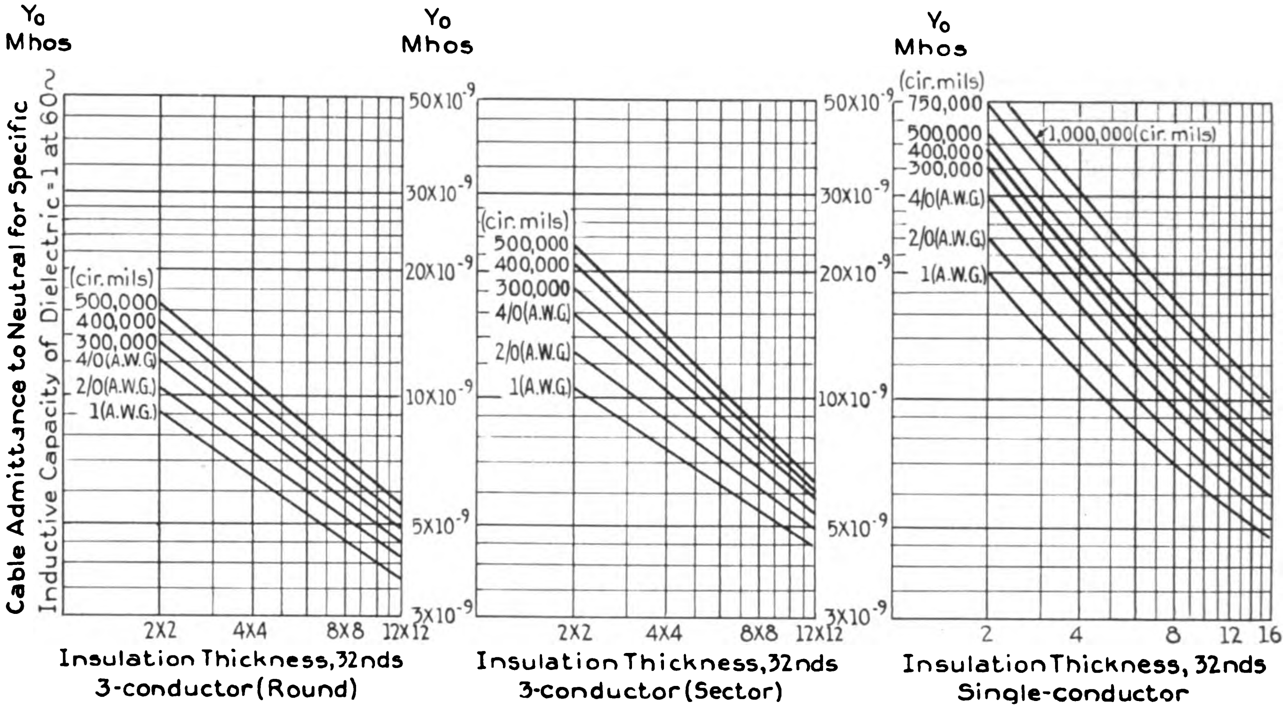
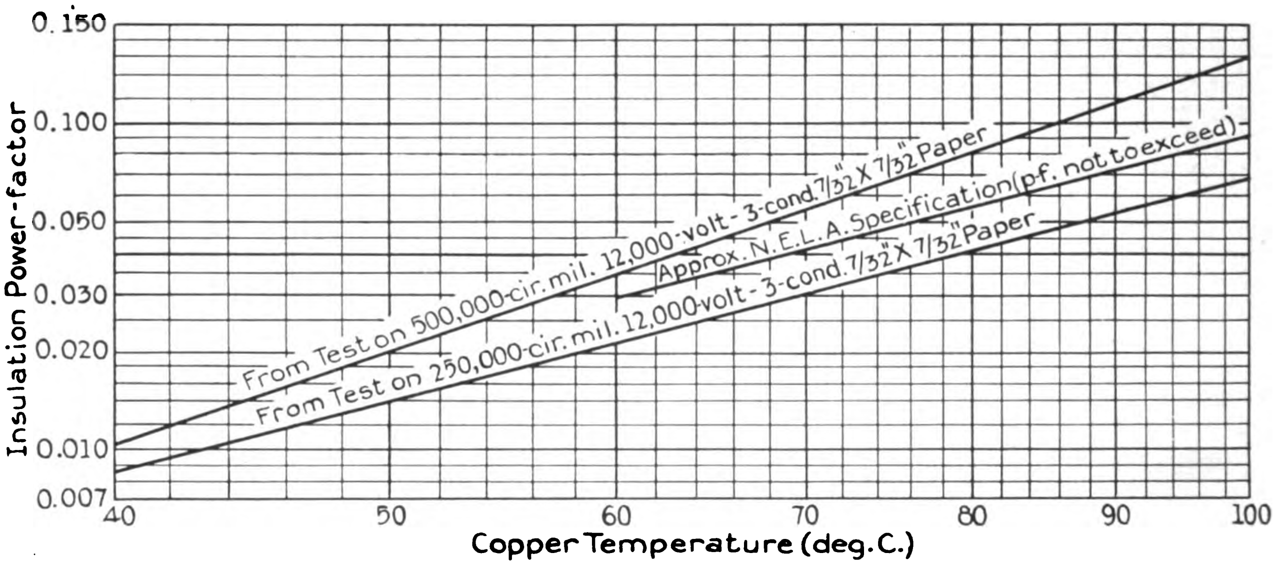
⁽¹⁾"Notes on Underground Conduits and Cables," by C. T. Mosman, *Trans. of A.I.E.E.*, 1912.

of the structure. The total loss from the middle eight loaded ducts (assuming uniform distribution of losses) was $\frac{8}{80}$ watt for one watt per foot of the structure. This loss must pass to the next outer row of ducts through twelve duct walls with air on both sides. The average drop through each duct wall per watt per foot, then, is $0.06 \times \frac{80}{8} \times 12$, or 7.2 deg. C. The total heat from the middle twenty-four cables must similarly pass through twenty duct walls, and the average drop per duct wall per watt per foot is $0.08 \times \frac{80}{24} \times 20$, or 5.33 deg. C. The total heat from the middle forty-eight cables must pass through forty-nine duct walls and the average drop per duct wall per watt per foot is $0.07 \times \frac{80}{48} \times 49$, or 5.7 deg. C.



(a). Dielectric Loss Charts



(b). Some 60-cycle P-f. Curves for Typical Paper Insulation

Fig. 3. Charts for Determination of Dielectric Losses

Charging Current Per Conductor in Amperes Per Foot = Y_o × Volts to Neutral × Specific Inductive Capacity of Insulation.

Total Dielectric Loss for Three Conductors of a 3-phase Group in Watts Per Foot of Run = $3 Y_o \times (\text{Volts to Neutral})^2 \times$ Specific Inductive Capacity of Insulation × Power-factor of Insulation at Copper Temperature.

The loss per cable of a 3-phase group of single-conductor cables is one-third of the total.

Specific Inductive Capacity of Impregnated Paper = 2.5 to 4.0. (Use 3.5 for Moden Cable; 2.5 for Rosin-oil Impregnated Cable.)

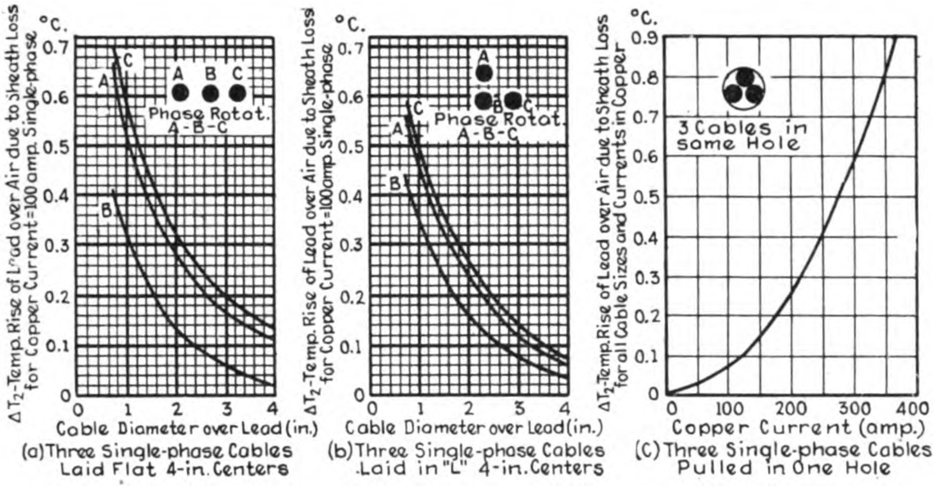
Specific Inductive Capacity of Varnished Cambric = 4 to 6.

For cables with belt insulation less than conductor insulation, use same value of Y_o as for cable with belt and conductor insulation thickness each equal to $\frac{3}{4}$ conductor insulation + $\frac{1}{4}$ belt insulation. Thus Y_o for $\frac{8}{32}$-in. by $\frac{4}{32}$-in. will be the same as Y_o for $\frac{7}{32}$-in. by $\frac{7}{32}$-in.

Similar analyses of other tests, together with this one, give an average temperature rise of about 6 deg.

C. per watt per foot per duct wall with air on both sides of the wall (*i.e.*, X), and about 3 deg. C. per watt per foot per duct wall with air on one side of the wall (*i.e.*, Y).

The correction curves in Fig. 6, for partially filled banks, are plots of about 50 computed cases.



(a) Three Single-phase Cables Laid Flat 4-in. Centers
(b) Three Single-phase Cables Laid in "L" 4-in. Centers
(C) Three Single-phase Cables Pulled in One Hole

Fig. 4. Charts Giving Lead Sheath Losses in Single-conductor Cable

In (*a*) and (*b*) the sheath loss temperature rises are for a copper current of 100 amp. These temperature rises vary as the square of the current flowing in the copper core. The values in (*c*) hold for all cable diameters.

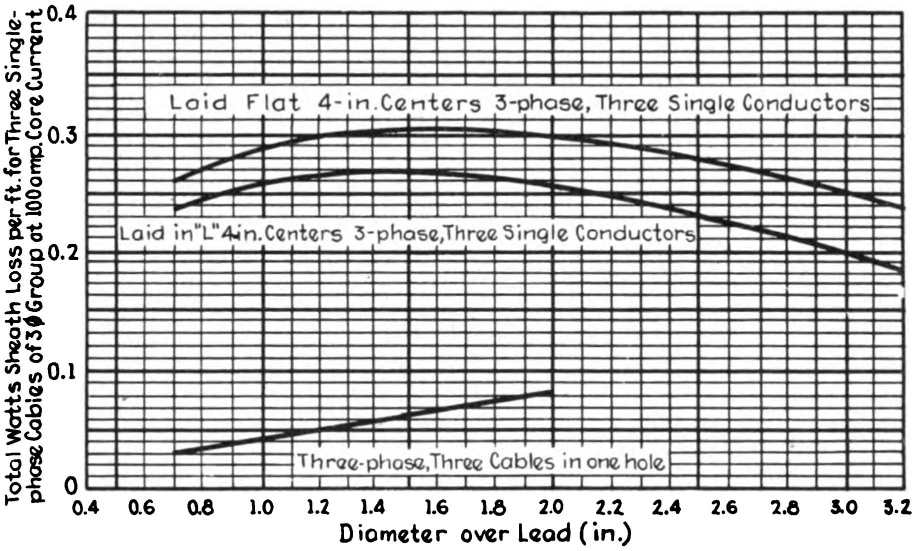


Fig. 5. Lead Sheath Loss Curves, Showing Total Watts Loss Per Foot of Run for a 3-phase Group of Three Single-conductor Cables

Curves are plotted for a copper current of 100 amp. Watts loss in sheath varies as square of copper current. For average watts loss per cable, use ⅓ of chart watts.

ΔT_4: The Temperature Rise of the Outer Surface of the Outer Wall of the Duct Bank Structure, Due to the Total Bank Loss

For the outer surface, $\Delta T_4 = Q_m h_b$, where Q_m is the mean total bank loss over twenty-four hours; h_b has been defined before.

There have been simple theories proposed for the determination of this temperature drop, in which it is considered that the bank loss heat flows only to the earth's surface. These theories lead to the conclusion that the duct bank's outer surface can never be cooler than the earth's surface. Such a conclusion is obviously incorrect.

For all practical purposes it may be considered that the duct bank sends heat to two planes at temperatures unaffected by the duct bank heat. One of these planes is at the earth's surface; the other fifteen feet or so below the duct bank. The temperature of the first plane, of course, varies seasonally, while the temperature of the second plane remains substantially the same the year round. On the basis of these assumptions, it may be shown that $\Delta T_4 +$ "sink" temperature

$$= 0.368\, Q_m S \left\{ \frac{\log_{10} \dfrac{2h+2w-\pi h+4\pi d}{2h+2w} \log_{10} \dfrac{2h+2w-\pi h+60\pi}{2h+2w}}{\log_{10} \dfrac{2h+2w-\pi h+4\pi d}{2h+2w} + \log_{10} \dfrac{2h+2w-\pi h+60\pi}{2h+2w}} \right\} + T_e$$

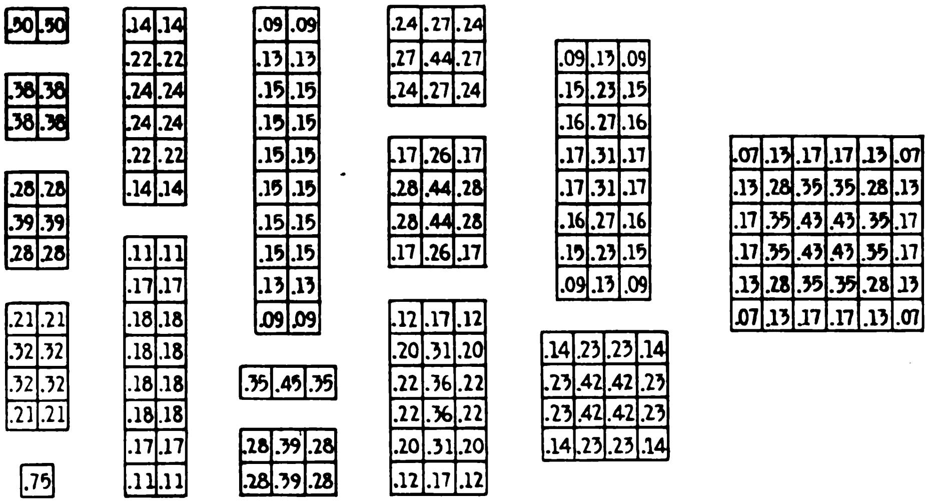
Fortunately the selection of the depth of the second assumed plane, within reasonable limits, has very little effect on the results.

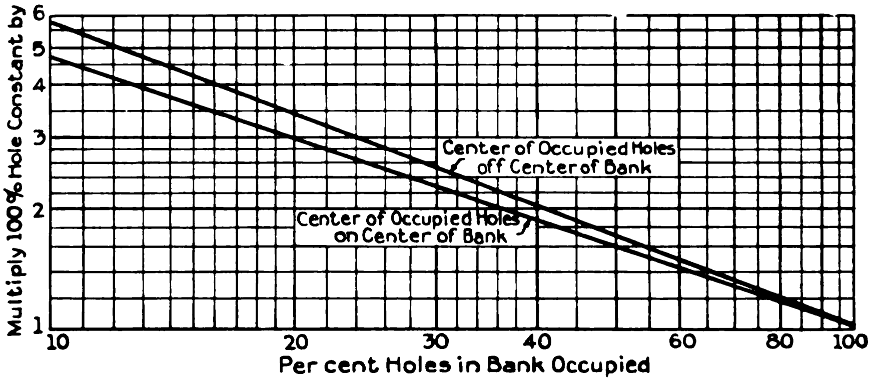
From the foregoing, it is apparent that the "sink" temperature is just the temperature of the adjacent undisturbed earth. The temperature rise ΔT_4 is charted in Fig. 8. To make use of this chart, it is necessary to know something about the soil conditions, in order to select the proper value of S, the soil resistivity. The thermal resistivity of the soil is rather sensitive to moisture content. It is sometimes helpful to dry out a typical sample of the soil through which the duct bank runs, in order to get some idea of the moisture content. A few per cent should be allowed for safety in a determination of this sort, since the soil immediately adjacent the duct bank may become partially dried out by the duct bank heat. The thermal resistivities of typical materials are given in Table I.

Undisturbed Earth Temperatures

Earth temperatures vary seasonally and with location. The amount of seasonal variation depends upon the depth below the earth's surface. The annual mean temperature is very nearly the same for all depths down to about 10 or 15 ft., increasing with greater depth. The maximum and minimum occur respectively in August and February in the north temperate zone. The available data show a slight time lag with depth, for these maximum and minimum temperatures. Some typical curves of earth temperatures at duct levels are shown in Fig. 9.

Hole Constants for Various Duct Banks 100% Occupied
Approximately Uniformly Loaded


.50 .50
.38 .38 / .38 .38
.28 .28 / .39 .39 / .28 .28
.21 .21 / .32 .32 / .32 .32 / .21 .21
.75
.14 .14 / .22 .22 / .24 .24 / .24 .24 / .22 .22 / .14 .14
.11 .11 / .17 .17 / .18 .18 / .18 .18 / .18 .18 / .18 .18 / .17 .17 / .11 .11
.09 .09 / .13 .13 / .15 .15 / .15 .15 / .15 .15 / .15 .15 / .15 .15 / .15 .15 / .13 .13 / .09 .09
.35 .45 .35
.28 .39 .28 / .28 .39 .28
.24 .27 .24 / .27 .44 .27 / .24 .27 .24
.17 .26 .17 / .28 .44 .28 / .28 .44 .28 / .17 .26 .17
.12 .17 .12 / .20 .31 .20 / .22 .36 .22 / .22 .36 .22 / .20 .31 .20 / .12 .17 .12
.09 .13 .09 / .15 .23 .15 / .16 .27 .16 / .17 .31 .17 / .17 .31 .17 / .16 .27 .16 / .15 .23 .15 / .09 .13 .09
.14 .23 .23 .14 / .23 .42 .42 .23 / .23 .42 .42 .23 / .14 .23 .23 .14
.07 .13 .17 .17 .13 .07 / .13 .28 .35 .35 .28 .13 / .17 .35 .43 .43 .35 .17 / .17 .35 .43 .43 .35 .17 / .13 .28 .35 .35 .28 .13 / .07 .13 .17 .17 .13 .07



Curve for Determining Hole Constants for Banks Having Less than 100% of Holes Occupied

Fig. 6. Charts for Determination of Temperature Rise of Duct Air Over Duct Bank Surface

Example 1: Four by three Duct Bank. Total watts per foot of bank = 40. All holes in bank occupied. Temperature rise of air in corner hole over surface of bank = 0.17 × 40 = 6.8 deg. C.

Example 2: Four by three Duct Bank. Total watts per foot of bank = 20. Upper and lower three holes filled (6 cables). Temperature rise of corner hole over bank surface = 0.17 × 1.6 × 20 = 5.4 deg. C. Hole spacing assumed as approximately four inches.

TABLE I

THERMAL RESISTANCES

Material and Condition	Resistivity Deg. C. Per Watt for a Foot Cube	Authority
Concrete—Stone	3.6	Kent's Handbook
Concrete—Cinder	9.6	Kent's Handbook
Concrete—Dry	4.4	Poensgen
Yellow Builders' Sand—Dry	11.1	Shanklin
Yellow Builders' Sand—2 per cent Wet	9.2	Shanklin
Yellow Builders' Sand—4 per cent Wet	6.8	Shanklin
Yellow Builders' Sand—6 per cent Wet	4.8	Shanklin
Yellow Builders' Sand—8 per cent Wet	3.4	Shanklin
White Sand—Dry and Fine	13.2	Kennelly
Quartz Sand—Dry, Medium Fine	12.4	Ingersoll & Koepp
Yellow Sandy Clay Soil—Dry	12.1	Shanklin
Yellow Sandy Clay Soil— 2 per cent Wet	11.6	Shanklin
Yellow Sandy Clay Soil— 4 per cent Wet	11.2	Shanklin
Yellow Sandy Clay Soil— 6 per cent Wet	9.7	Shanklin
Yellow Sandy Clay Soil— 8 per cent Wet	7.4	Shanklin
Yellow Sandy Clay Soil—10 per cent Wet	5.4	Shanklin
Yellow Sandy Clay Soil—12 per cent Wet	3.7	Shanklin
Yellow Sandy Clay Soil—14 per cent Wet	2.4	Shanklin
Sandy Clay (Wetness Undetermined)	3.6	Ingersoll and Koepp
Calcareous Earth (Water Saturated)	4.6	Ingersoll and Koepp
Water at 25 deg. C	5.8	Kent's Handbook

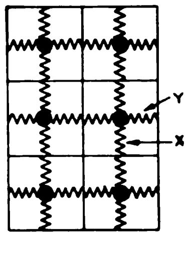


Fig. 7. Thermal Resistance Grid Diagram Used in Computing the Hole Constants for a Three by Two Duct Bank

Allowable Copper Temperatures

The following are the maximum allowable copper temperatures for impregnated-paper-insulated cables as given by the N.E.L.A.:

Kilovolts	Temperature Deg. C.
0–5	85
10	80
15	75
20	70
25	65
30	60
45	60

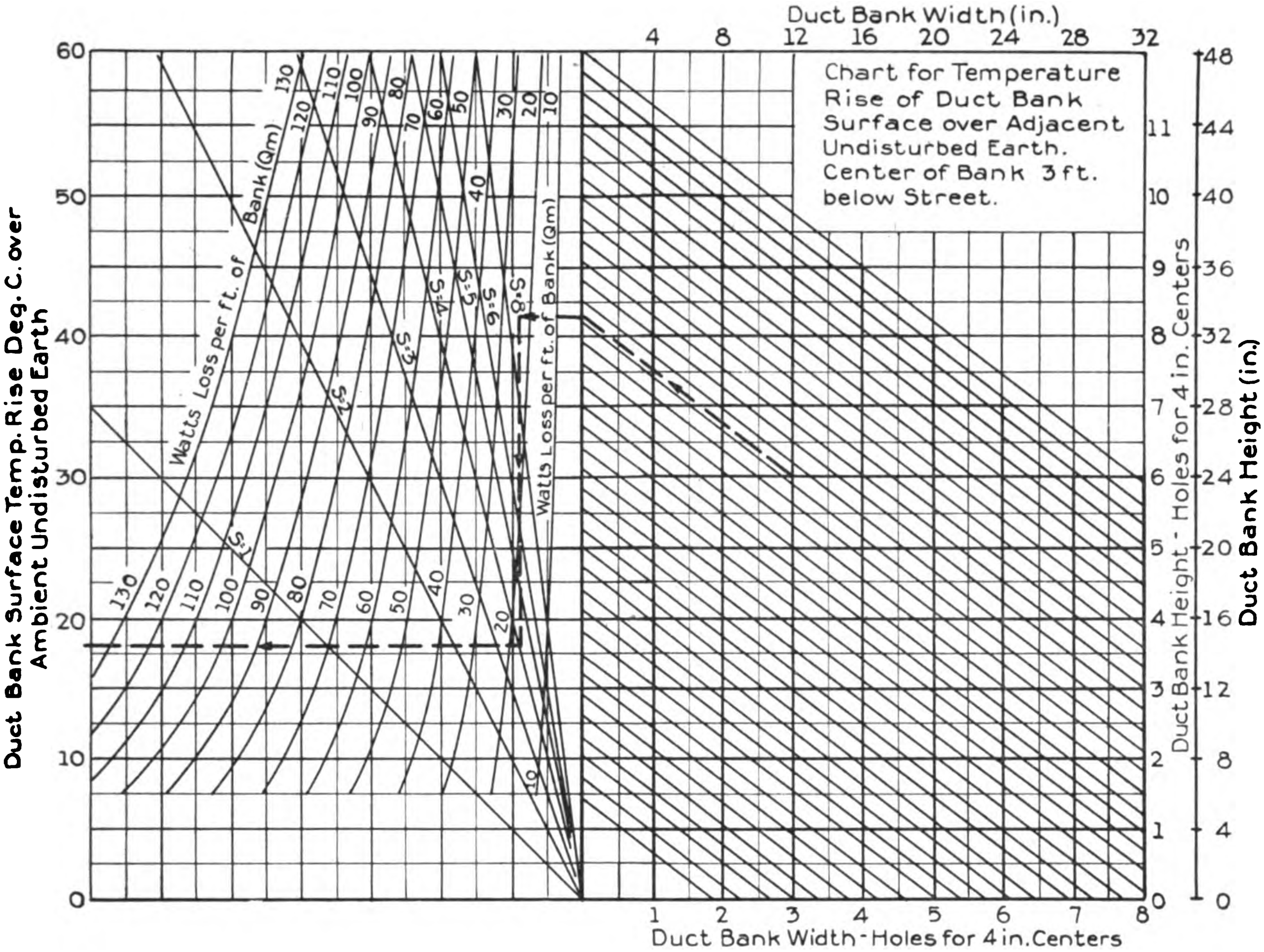


Fig. 8. Chart for Determination of the Temperature Rise (ΔT_4) of the Outer Surface of the Duct Bank Over Adjacent Undisturbed Earth

A.I.E.E. Standards give the following, where t is the allowable copper temperature in deg. C., and E is the r.m.s. value of the e.m.f. between conductors, in kilovolts:

For impregnated paper, $t = 90 - E$
For varnished cambric, $t = 75 - E$
For rubber, $t = 60 - E/4$

Example

A three by six duct bank will be assumed, filled with cables as shown in Fig. 10 and listed in Table II, on an industrial nine-hour load.

Total bank loss, average over peak hour (Q), is 50.2 watts per foot of duct bank structure.

Total bank loss, average over 24 hours (Q_m), is 18.8 watts per foot of duct bank structure.

Three single-conductor 12-kv. cables are to be put into ducts No. 1, No. 4, and No. 7. These cables will be 500,000-cir. mil, insulated with $\frac{12}{32}$ in. of impregnated paper, with an outside diameter of 1.81 inches ($\frac{1}{8}$-in. lead). If the phase rotation is A-B-C, it is at once obvious that cable C, which will have the greatest sheath loss of the three cables, should be put into duct No. 1 since this is the coolest duct of the three.

A current of 340 amp. will be assumed as a first approximation. The maximum allowable copper temperature will be 80 deg. C.

At 340 amp., the total copper loss for group (Fig. 2) is 3×3.05 or 9.2 watts per ft.

At 340 amp., the total sheath loss for group (Fig. 5) is $0.3 \times \left(\frac{340}{100}\right)^2$ or 3.5 watts per ft.

Dielectric loss for group is

$$3 \times 9.6 \times 10^{-9} \times \frac{(12{,}000)^2}{3} \times 3.5 \times 0.1$$

or 0.5 watts per ft.

The total bank loss with these three cables is 63.4 for Q and 23.7 watts per foot for Q_m.

From Fig. 1, ΔT_1 for each conductor is $5.7\times\left(\frac{9.2+0.5}{3}\right)$ or 18.5 deg. C.

From Fig. 4,

$$\Delta T_2 \text{ is } 0.3\times\left(\frac{340}{100}\right)^2=3.6 \text{ deg. C. for Cable } A.$$

$$0.15\times\left(\frac{340}{100}\right)^2=1.7 \text{ deg. C. for Cable } B.$$

$$0.34\times\left(\frac{340}{100}\right)^2=3.9 \text{ deg. C. for Cable } C.$$

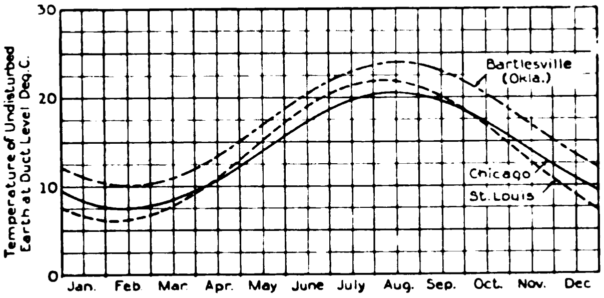


Fig. 9. Graphs Showing Seasonal Variations of Earth Temperature

The next question is the determination of the hole constants in order to compute ΔT_3. The bank is 11/18 or 61 per cent occupied. If the filled ducts had equal losses, the hole constants would be (from Fig. 6):

For Duct No. 1, $1.5\times0.12=0.18$
For Duct No. 4, $1.5\times0.20=0.30$
For Duct No. 7, $1.5\times0.22=0.33$

The average loss per filled duct is 63.4/11 or 5.77 watts per foot. The losses in the ducts which we are considering is 4.9 watts per foot. Since the losses in the ducts neighboring the ducts which will be used for the new cables are also lower than the average, we will use 84 per cent of the hole constants for the equal-loss condition. Thus

For Duct No. 1, the hole constant is 0.15
For Duct No. 4, the hole constant is 0.25
For Duct No. 7, the hole constant is 0.28

and

ΔT_3 for Duct No. 1 is $0.15\times63.4=9.5$ deg. C.
ΔT_3 for Duct No. 4 is $0.25\times63.4=16$ deg. C.
ΔT_3 for Duct No. 7 is $0.28\times63.4=17.8$ deg. C.

From the chart in Fig. 8, assuming soil resistivity $S=4$, ΔT_4 is 18.2 deg. C.

No. 1	No. 2	No. 3 8.4 Watts
No. 4	No. 5 3.9 Watts	No. 6
No. 7	No. 8	No. 9
No. 10 3.9 Watts	No. 11 6.9 Watts	No. 12 7.2 Watts
No. 13 7.2 Watts	No. 14	No. 15
No. 16 4.3 Watts	No. 17	No. 18 8.4 Watts

Fig. 10. Diagram of Cable Arrangement Given in Table II

For Chicago conditions in August, the undisturbed adjacent earth temperature is 20.5 deg. C. (Fig. 9).

The total temperature of the copper in Cable A, which is the hottest of the three, is

$$18.5+3.6+17.8+18.2+20.5=78.6 \text{ deg. C.}$$

A recomputation at 350 amp. will show that this value of current will give the maximum temperature allowable, *i.e.*, 80 deg. C.

Acknowledgment

The author wishes to express his appreciation to Mr. R. W. Drake, without whose comments, suggestions, and criticisms, this paper would not have been possible.

TABLE II

Duct No.	Condition of Duct, and Description of Cable	Current, Amp.	q_c	q_d	q_s
1	To be used	?	?	?	?
2	Empty	....	....	....	....
3	440-volt 3-conductor 500,000-cir. mil	325	8.4	....	....
4	To be used	?	?	?	?
5	12-kv. 3-conductor 4/0 round	150	3.6	0.3	....
6	Empty	....	....	....	....
7	To be used	?	?	?	?
8	Empty	....	....	....	....
9	Empty	....	....	....	...
10	12-kv. 3-conductor 4/0 round	150	3.6	0.3	....
11	440-volt 3-conductor 350,000-cir. mil	250	6.9	....	....
12	440-volt 3-conductor 500,000-cir. mil	300	7.2	....	....
13	440-volt 3-conductor 500,000 cir.-mil	300	7.2	....	....
14	Empty	....	....	....	....
15	Empty	....	....	....	....
16	12-kv. 3-conductor 400,000-cir. mil sector	200	3.9	0.4	....
17	Empty	....	....	....	....
18	440-volt 3-conductor 500,000-cir. mil	325	8.4	....	....

APPENDIX A: Derivation of h_i for Sector Cables

If the copper core were one round copper conductor, the thermal resistance of an annular element at a radius p would be,

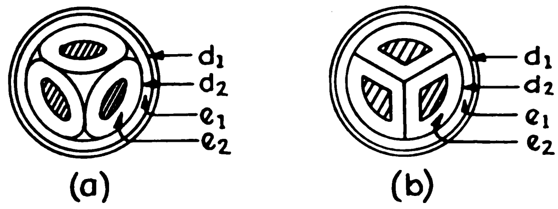
$$dh_1 = \frac{K\,dp}{2\pi p}$$

and
$$h_i = \frac{K}{2\pi}\int_{(d_2-2e_2)}^{d_1} \frac{dp}{p} = \frac{K}{2\pi} \log_e \frac{d_1}{d_2-2e_2}$$

If the cable were as shown in Fig. 11(b), and it be assumed that heat is emitted only from the surface of the copper adjacent the lead, then, very nearly,

$$h_i = \frac{K}{2\pi}\left(\frac{2\pi d_2}{2\pi d_2 - 6e_2}\right) \log_e \frac{d_1}{d_2-2e_2}$$

The first relation for h_i gives low results, since a continuous copper surface parallel to the sheath for 360 deg. of the circumference does not exist in the actual sector cable, Fig. 11(a). Even though the copper in the cable is not so favorably shaped for heat flow as is shown in (b), Fig 11, the fact that the heat which flows to the lead from the sides of the copper was neglected makes the second relation give high results. The correct relation is somewhere between the two; not halfway, but nearer the second than the first. It is found that



Actual Simplified for analysis

Fig. 11. Sector Cable Sections

$$h_i = \frac{K}{2\pi}\,\frac{2d_2}{2d_2-e_2} \log_e \frac{d_1}{d_2-2e_2}$$

or

$$h_i = 0.368\,K \frac{2d_2}{2d_2-e_2} \log_{10} \frac{d_s}{d_2-2e_2}$$

This gives results which check fairly well with measurements. The fact that the sector shapes vary with different manufacturers, makes further refinement in the formulating of h_i of little value.

APPENDIX B: Currents in the Sheaths of Single Conductor Cables in Three-phase Groups

The cases considered herein will neglect proximity effect, and will assume the three sheaths solidly bonded but grounded at not more than one point. The phase rotation will be A-B-C. The following notation will be used:

Core current in A, $\boldsymbol{I}_a = I\ (-0.5+j0.866)$
Core current in B, $\boldsymbol{I}_b = I\ (1+j0)$
Core current in C, $\boldsymbol{I}_c = I\ (-0.5-j0.866)$
A sheath current, $\boldsymbol{i}_a = i_a' + ji_a''$
B sheath current, $\boldsymbol{i}_b = i_b' + ji_b''$
C sheath current, $\boldsymbol{i}_c = i_c' + ji_c''$
Mean sheath radius, p
Center spacing, s
Frequency, f; and $2\pi f = \omega$
Flux which surrounds sheath of A, $\boldsymbol{\phi}_a$
Flux which surrounds sheath of B, $\boldsymbol{\phi}_b$
Flux which surrounds sheath of C, $\boldsymbol{\phi}_c$
Voltage induced in sheath of A, $\boldsymbol{E}_a$
Voltage induced in sheath of B, $\boldsymbol{E}_b$
Voltage induced in sheath of C, $\boldsymbol{E}_c$
Resistance of sheath per centimeter, R_s
All logarithms to base e
Bold-faced characters represent vector quantities.

Case I: Equilateral Spacing (Fig. 12)

This being a symmetrical arrangement we need investigate but one cable. The other two cable sheaths will have currents and losses of equal magnitude.

The flux which surrounds the sheath of cable B is:

$$\boldsymbol{\phi}_b = \int_p^\infty \frac{2}{10}\,(\boldsymbol{I}_b+\boldsymbol{i}_b)\,\frac{dx}{x} + \int_s^\infty \frac{2}{10}\,(\boldsymbol{I}_a+\boldsymbol{i}_a+\boldsymbol{I}_c+\boldsymbol{i}_c)\,\frac{dx}{x}$$

For the conditions which we have assumed $\boldsymbol{i}_a+\boldsymbol{i}_b+\boldsymbol{i}_c=0$, so

$$\boldsymbol{\phi}_b = \int_p^s \frac{2}{10}\,(\boldsymbol{I}_b+\boldsymbol{i}_b)\,\frac{dx}{x} = 2\,(I+i_b'+ji_b'') \log \frac{s}{p}\,10^{-1}$$

The voltage induced in the sheath of cable B is:

$$\boldsymbol{E}_b = -j\omega\,\boldsymbol{\phi}_b 10^{-8} = 2\omega\,(i_b''-jI-ji_b') \log \frac{s}{p}\,10^{-9}$$

Since $\boldsymbol{E}_a$ and $\boldsymbol{E}_c$ are similarly $-\ 2\omega j\ (\boldsymbol{I}_a+\boldsymbol{i}_a) \log \frac{s}{p}\ 10^{-9}$ and $-2\omega j\ (\boldsymbol{I}_c+\boldsymbol{i}_c) \log \frac{s}{p}\ 10^{-9}$, then $\boldsymbol{E}_a+\boldsymbol{E}_b+\boldsymbol{E}_c=0$, and there is no residual voltage. Therefore

$$\boldsymbol{E}_b = R_s\,(i_b'+ji_b'') = 2\omega\,(i_b''-jI-ji_b') \log \frac{s}{p}\,10^{-9}$$

and

$$i_b' R_s = 2\omega i_b'' \log \frac{s}{p}\,10^{-9},\ i_b'' R_s = -2\omega\,(I+i_b') \log \frac{s}{p}\,10^{-9}$$

whence

$$i_b'' = -I\,\frac{2\omega R_s \log \frac{s}{p}}{R_s^2 + 10^{-18}\left(2\omega \log \frac{s}{p}\right)^2}\,10^{-9}$$

$$i_b' = -I\,\frac{\left(2\omega \log \frac{s}{p}\right)^2}{R_s^2 + 10^{-18}\left(2\omega \log \frac{s}{p}\right)^2}\,10^{-18}$$

$$i_b^2 R_s = I^2\,\frac{R_s\left(2\omega \log \frac{s}{p}\right)^2}{R_s^2 + 10^{-18}\left(2\omega \log \frac{s}{p}\right)^2}\,10^{-18}$$

The last relation gives the sheath loss in watts per centimeter for each cable in the group. When three cables are pulled into the same duct, the values obtained by this relation should be increased by about 20 or 30 per cent to allow for proximity effect. A graphical representation with this allowance made is shown in Fig. 5.

Case II: Cables Laid Flat—Equal Spacing (Fig. 13)

The flux which surrounds cable A is

$$\phi_a=\int_p^\infty \frac{2}{10}(I_a+i_a)\frac{dx}{x}+\int_s^\infty \frac{2}{10}(I_b+i_b)\frac{dx}{x}+\int_{2s}^\infty \frac{2}{10}(I_c+i_c)\frac{dx}{x}$$

and

$$\phi_b=\int_p^\infty \frac{2}{10}(I_b+i_b)\frac{dx}{x}+\int_s^\infty \frac{2}{10}(I_a+I_c+i_a+i_c)\frac{dx}{x}$$

$$\phi_c=\int_p^\infty \frac{2}{10}(I_c+i_c)\frac{dx}{x}+\int_s^\infty \frac{2}{10}(I_b+i_b)\frac{dx}{x}+\int_{2s}^\infty \frac{2}{10}(I_a+i_a)\frac{dx}{x}$$

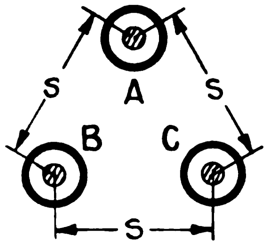


Fig. 12. Cable Spacing for Case *I:* Equilateral

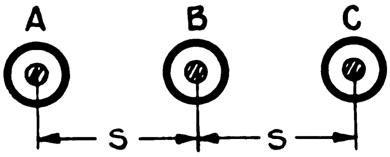


Fig. 13. Cable Spacing for Case *II:* Flat, Equal Spacing

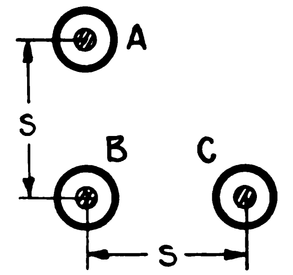


Fig. 14. Cable Spacing for Case *III:* Laid in "L," Equal Spacing

For the assumed conditions, $i_a+i_b+i_c=0$, so

$$\phi_a=\int_p^{2s} \frac{2}{10}(I_a+i_a)\frac{dx}{x}+\int_s^{2s} \frac{2}{10}(I_b+i_b)\frac{dx}{x}$$

$$=\frac{2}{10}(I_a+i_a)\log\frac{2s}{p}+\frac{2}{10}(I_b+i_b)\log 2$$

$$\phi_b=\int_p^{s} \frac{2}{10}(I_b+i_b)\frac{dx}{x}=\frac{2}{10}(I_b+i_b)\log\frac{s}{p}$$

$$\phi_c=\int_p^{2s} \frac{2}{10}(I_c+i_c)\frac{dx}{x}+\int_s^{2s} \frac{2}{10}(I_b+i_b)\frac{dx}{x}$$

$$=\frac{2}{10}(I_c+i_c)\log\frac{2s}{p}+\frac{2}{10}(I_b+i_b)\log 2$$

and the induced voltages in the sheaths are

$$E_a=-2j\omega\left[(I_a+i_a)\log\frac{2s}{p}+(I_b+i_b)\log 2\right]10^{-9} \quad (1)$$

$$E_b=-2j\omega\,(I_b+i_b)\log\frac{s}{p}\,10^{-9} \quad (2)$$

$$E_c=-2j\omega\left[(I_c+i_c)\log\frac{2s}{p}+(I_b+i_b)\log 2\right]10^{-9} \quad (3)$$

Since $E_a+E_b+E_c\neq 0$, there will be a residual voltage, E_r, and

$$i_aR_s+E_r=E_a,\quad i_bR_s+E_r=E_b,\quad i_cR_s+E_r=E_c$$

so $\quad 3E_r=E_a+E_b+E_c=[-2j\omega\,(I_b+i_b)\log 2]\,10^{-9}$

Substituting the value of E_r obtained from this relation into Equations (1), (2), and (3)

$$i_aR_s=-\left[2j\omega\,(I_a+i_a)\log\frac{2s}{p}+\frac{4}{3}j\omega\,(I_b+i_b)\log 2\right]10^{-9} \quad (4)$$

$$i_bR_s=-\left[2j\omega\,(I_b+i_b)\log\frac{s}{p}-\frac{2}{3}j\omega\,(I_b+i_b)\log 2\right]10^{-9} \quad (5)$$

$$i_cR_s=-\left[2j\omega\,(I_c+i_c)\log\frac{2s}{p}+\frac{4}{3}j\omega\,(I_b+i_b)\log 2\right]10^{-9} \quad (6)$$

From (5)

$$i_b=-I\,\frac{2j\omega\log\frac{s}{p}-\frac{2}{3}j\omega\log 2}{10^9 R_s+2j\omega\log\frac{s}{p}-\frac{2}{3}j\omega\log 2}\,10^{-8} \quad (7)$$

Substitution of Equation (7) in (4) and (5) gives Equations (8) and (9), which follow.

$$i_a=I\,\frac{\omega(\sqrt{3}+j)\left[10^9 R_s\log\frac{2s}{p}+2j\omega\log\frac{2s}{p}\left(\log\frac{s}{p}-\frac{1}{3}\log 2\right)\right]-\frac{4}{3}j\omega R_s\,10^9\log 2}{\left[10^9 R_s+2j\omega\left(\log\frac{s}{p}-\frac{1}{3}\log 2\right)\right]\left(10^9 R_s+2j\omega\log\frac{2s}{p}\right)} \quad (8)$$

$$i_c=I\,\frac{\omega(-\sqrt{3}+j)\left[10^9 R_s\log\frac{2s}{p}+2j\omega\log\frac{2s}{p}\left(\log\frac{s}{p}-\frac{1}{3}\log 2\right)\right]-\frac{4}{3}j\omega R_s\,10^9\log 2}{\left[10^9 R_s+2j\omega\left(\log\frac{s}{p}-\frac{1}{3}\log 2\right)\right]\left(10^9 R_s+2j\omega\log\frac{2s}{p}\right)} \quad (9)$$

Case III: Cables Laid in "L"—Equal Spacing (Fig. 14)

A similar analysis to that of Case *II* gives results that differ from the relations (7), (8), and (9), only in that $\frac{1}{2}\log\frac{2s^2}{p^2}$ is substituted for $\log\frac{2s}{p}$, and $\frac{1}{2}\log 2$ is substituted for $\log 2$.

The Current Impulse Transformer

High Current Values Obtained—Of the Order of 0.01 Sec. Duration—Applicable to Magnetizing Permanent Magnets—Description of Transformer—Analysis of Factors—Design Calculations

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THE operating principle of the current impulse transformer makes use of the characteristics that would be exhibited by a conventional type of transformer under unidirectional, intermittent excitation. Thus, when a steady unidirectional potential is applied to the primary (high-tension) terminals of an ordinary transformer having a short-circuited secondary of one turn, a high unidirectional current impulse or transient is induced in the secondary in the reverse direction from the current in the primary.

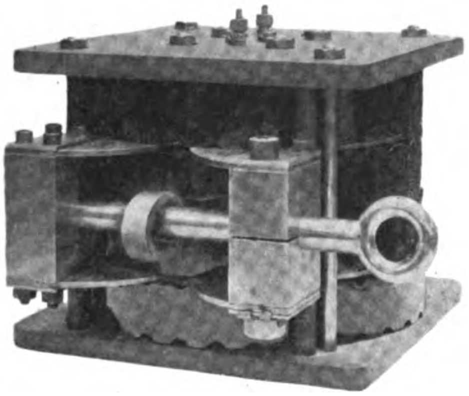


Fig. 1. Current Impulse Transformer with Open Magnetic Circuit and 20,000-amp. Secondary

When the primary circuit is broken a current is induced in the secondary in the same direction as in the primary.

The peak value of the transient secondary current, neglecting losses and magnetic leakage, approaches the numerical limit of one-half the primary ampere-turns when closing the circuit, and the primary ampere-turns when opening the circuit.

For example, if:

The primary voltage	=	100 volts
The primary resistance	=	20 ohms
The primary current	=	5 amp.
The primary turns	=	2000
The primary ampere-turns	=	10,000
The secondary turns	=	1

then the secondary current peak

On closing the circuit = 5,000 amp.
On opening the circuit = 10,000 amp.

The secondary may have any number of turns, but the ampere-turns will be the same. Usually there will be but one secondary turn as the object is to obtain the highest possible current.

This action makes feasible the generation of high-current transients by small, simple, and efficient means and is particularly useful in the excitation of permanent magnets of such form as to be unsuitable for excitation by electromagnets.

The scheme is analogous to that of any ordinary induction coil where a high-voltage impulse is produced in an open circuit, while in the current impulse transformer a high-current impulse is produced in a closed circuit.

The current impulse transformers that have been developed will now be described; following which a detailed analysis will be given of the electrical considerations involved in the design of this new type of direct-current transformer.

PART I: DESCRIPTION OF THE CURRENT IMPULSE TRANSFORMER

Transformer with Open Magnetic Circuit

A small current impulse transformer with open magnetic circuit is shown in Fig. 1 and is suitable for light work such as permanently magnetizing the magnet shown in position on the short-circuiting bar. It has a capacity of about 20,000 amp. which for this magnet is equivalent to 10,000 amp. continuous current. This difference is caused by the short duration of the transient, the flux being small.

Various forms of magnets were energized by this transformer at several values of current and the resulting magnetic strengths measured. Fig. 2 shows the relation of the magnetic strength and primary ampere-turns when exciting one magnet at a time.

Transformer with Closed Magnetic Circuit

A larger transformer, with closed magnetic circuit and capacity of 30,000 amp. secondary, is shown in Fig. 3 and its diagram of connections in Fig. 4. This transformer can be made to form part of an automatic machine for exciting double magnets. Other views are shown in Figs. 5, 6, and 7. It has a one-turn secondary, consisting of four copper sheets in parallel and interleaved with eight primaries.

The two magnets are excited in series on two copper plungers, which work through the terminal blocks.

All the operating motions are produced by d-c. plunger magnets, the whole sequence taking place within 1½ sec. after the closing of the trip switch, which is automatically opened at the end of the operation.

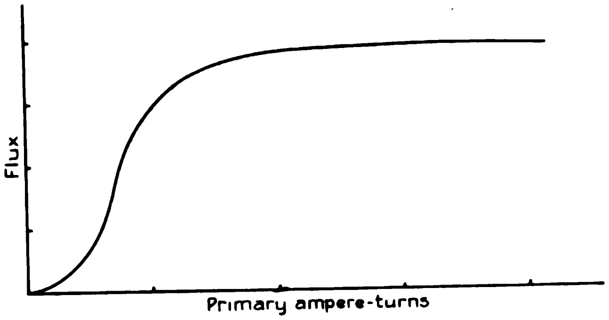


Fig. 2 Saturation Curve of Permanent Magnet Obtained by Using the Transformer Shown in Fig. 1

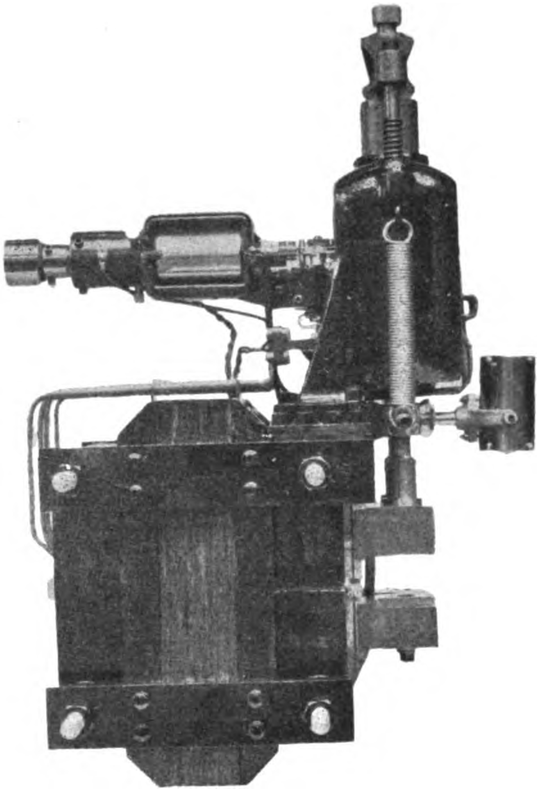


Fig. 3. Side View of Current Impulse Transformer with Closed Magnetic Circuit and 30,000-amp. Secondary

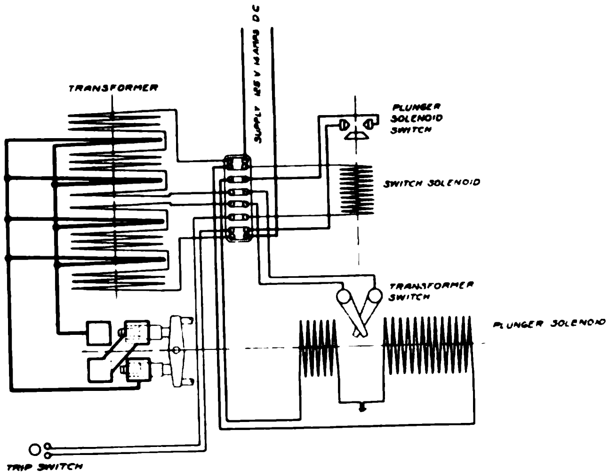

SUPPLY 125 V MAINS DC
TRANSFORMER
PLUNGER SOLENOID SWITCH
SWITCH SOLENOID
TRANSFORMER SWITCH
PLUNGER SOLENOID
TRIP SWITCH

Fig. 4. Connection Diagram of the Transformer Shown in Fig. 3

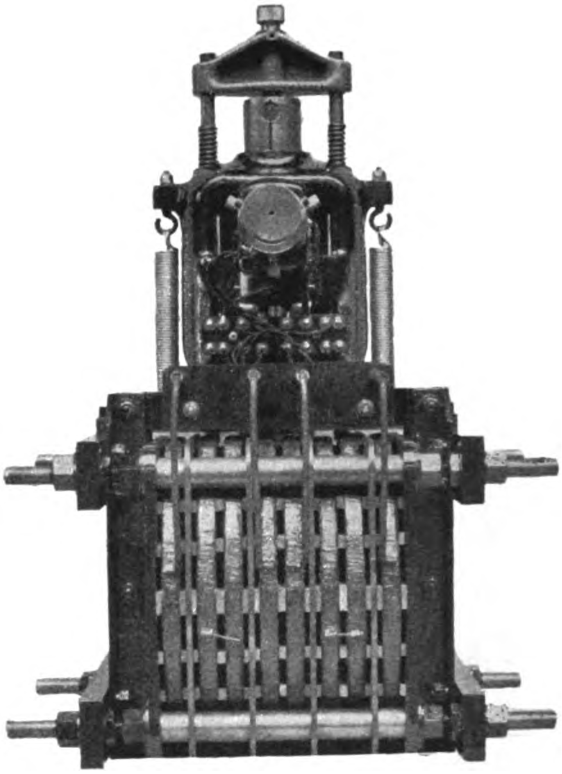


Fig. 5. Back View of the 30,000-amp. Current Impulse Transformer

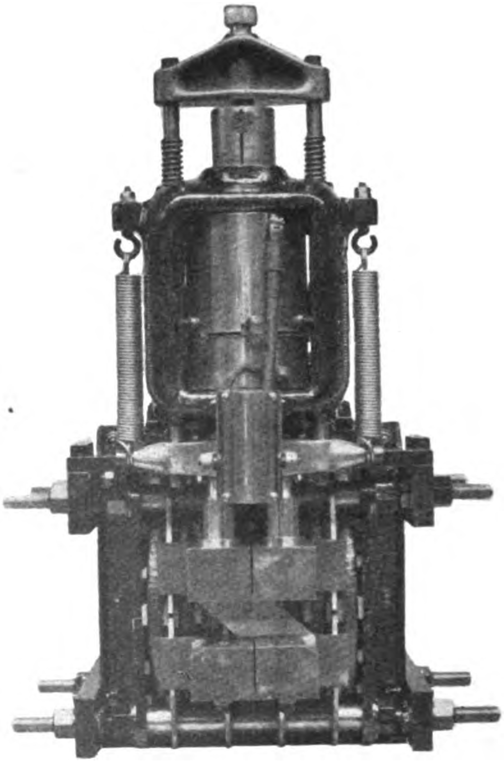


Fig. 6. Front View of the 30,000-amp. Current Impulse Transformer

High-speed Switch

An enlarged view of the high-speed switch is shown in Fig. 8. The two ball-bearing spindles carry the switch blades at the far end. These cross each other in wiping contact—scissors fashion—as indicated in Fig. 4, the action being single-pole.

The large plunger solenoid has two air gaps: a working gap about 2½ in. long and a blow-out gap for the switch about ¼ in. long.

The arc is drawn in a magnetic field near saturation. The use of the field of the operating solenoid for the magnetic blow-out eliminates the need for a special coil for the latter purpose.

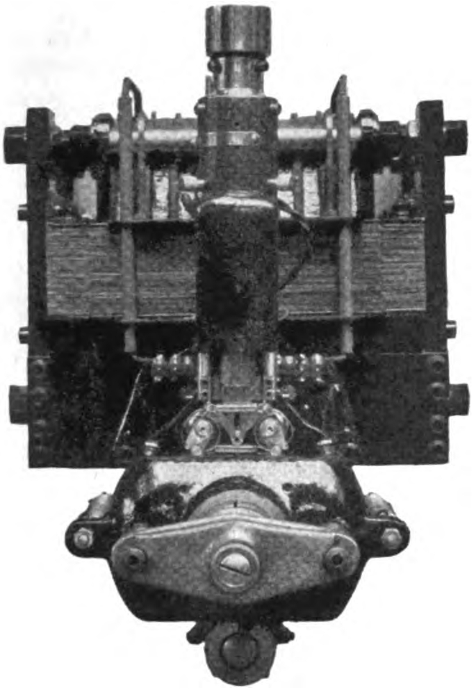


Fig. 7. Top View of the 30,000-amp. Current Impulse Transformer

The switch is closed by the switch solenoid operating on the toggle and is opened by a pair of helical springs. The single helical spring at the bottom takes the overshoot and the two C springs are designed to give way and prevent damage if the switch blades should jam.

The circuit is broken cleanly in about 0.002 sec., the arc being 4½ in. long and the maximum rise of voltage about 3000 with 125 volts applied.

This switch is perhaps the most important element in the whole device, the magnitude of the secondary terminal current being dependent on the speed of break. Fig. 9 shows the drop of primary current and the secondary current impulse of the transformer when using this switch.

Various other switches were tried and the time for complete opening of the circuit found to be approximately as given in Table I.

A condenser connected across the switch caused the circuit to oscillate and also absorbed energy from the magnetic field, for which reasons this common application of the condenser is not utilized in the current impulse transformer.

Solenoids

The mechanism is set by solenoids and returned by springs. The exciting coils are wound on metal spools with metal jackets, the small one being of brass and the large one of copper. This makes the action smooth and quiet, though powerful, the small plunger having a maximum force of about 100 lb. and the large one 600 lb.

With large currents and low voltages, perfect contact of the short-circuiting plungers is imperative.

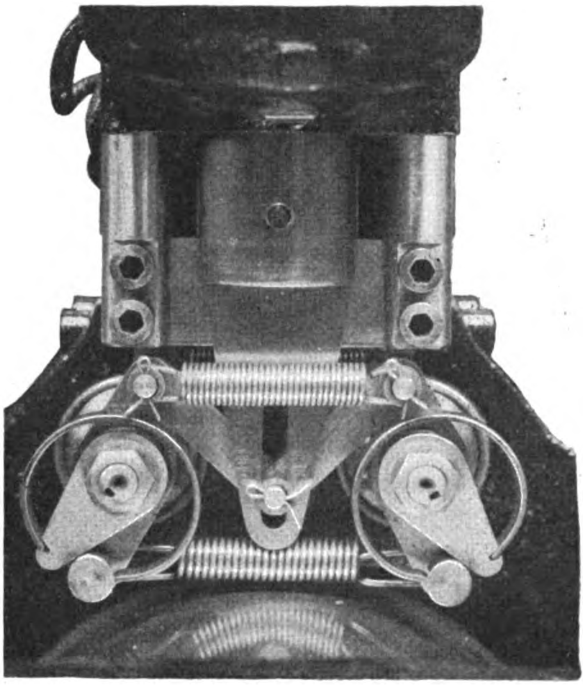


Fig. 8. High-speed Switch Used to Interrupt the Primary Current of the 30,000-amp. Current Impulse Transformer

The front end seats in a conical bushing and the rear end is split and expanded in a bushing by an internal steel cone forced in against a stiff spring by the main solenoid.

Comparison with Other Methods

The impulse method is especially well suited for permanently magnetizing those magnets which have small air gaps and which are not easily excited by an electromagnet.

TABLE I

Switch	Time in Sec.
Double-pole knife	0.043
Quick-break knife	0.017
Rotary	0.055
Mercury	0.008
Magnetic blow-out	0.002

Any method producing a large direct current for an instant is equally effective but is usually at a disadvantage on the score of size and cost of the apparatus.

As the source of direct current the current impulse transformer may be compared with a motor-generator thus:

Cost. The cost of the impulse transformer is but a fraction of that of the motor-generator.

Size. The transformer is much smaller than the motor-generator.

Power Input. An impulse transformer of great power (50,000 amp.) may be operated by a primary input of 3 kw. or less. The idle loss of a comparable motor-generator might be equal to this and the loss when excited several times as much.

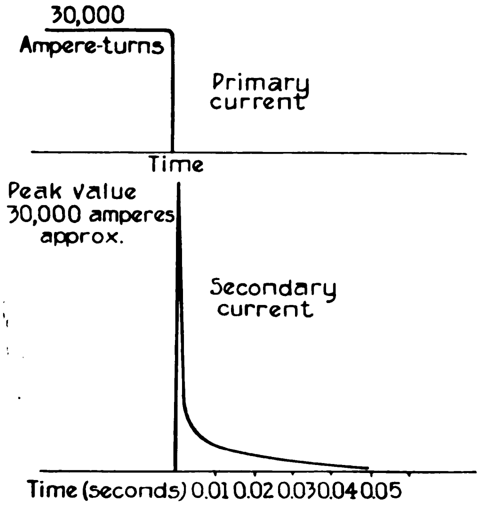


Fig. 9. Copy of Oscillograms of the Primary and Secondary Currents of the 30,000-amp. Current Impulse Transformer

Operation. The impulse transformer is well adapted to rapid automatic operation, using small and simple control devices. This advantage coupled with the small size, low input power, and general convenience of operation in many cases render it preferable to other magnetizing methods.

PART II: ACTIONS IN THE PRIMARY AND SECONDARY CIRCUITS CONSIDERED INDEPENDENTLY

For the sake of simplicity in a detailed explanation of the actions taking place in the primary and secondary circuits of this type of direct-current transformer, the actions will first be considered independently.

For maximum effect, the sequence of operation should be:

(1). Open the secondary
(2). Close the primary
(3). Close the secondary
(4). Open the primary.

The primary current rises slowly to a constant maximum value and falls instantly to zero.

The secondary current rises instantly to a maximum and falls slowly to zero.

The rise of primary and fall of secondary current is at a rate proportional to itself. That is, it is logarithmic and follows the exponential expression:

$$I = I_0\left(1 - \epsilon^{-\frac{R}{L}t}\right) \quad \text{for increasing primary current} \qquad (1)$$

and

$$I = I_0\,\epsilon^{-\frac{R}{L}t} \quad \text{for decreasing secondary current} \qquad (2)$$

where

I = instantaneous current at time t
I_0 = maximum current

R and L are resistance and inductance of winding involved. And

$\epsilon = 2.71828$ = base of Napierian Logarithms.

Derivation of Formulas

Equations (1) and (2) may be deduced from:

$$IR + L\frac{dI}{dt} = E \text{ for rise of current, and}$$
$$= 0 \text{ for fall of current.}$$

These expressions apply generally to any action varying at a rate proportional to itself, and the fundamental form:

$I = I_0\,\epsilon^{-\frac{R}{L}t}$, when suitably modified and elaborated is sufficient for the solution of all the circuit problems under consideration.

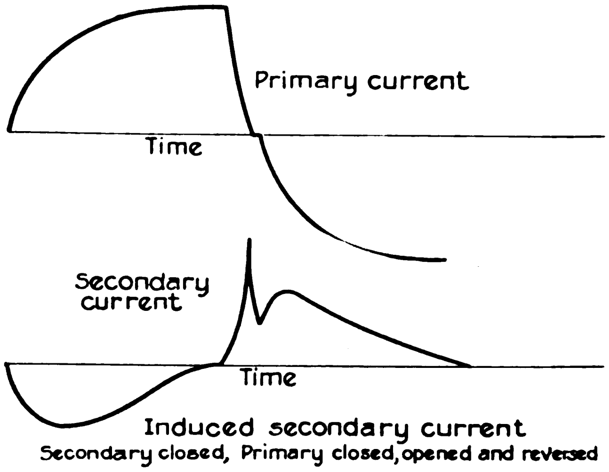


Fig. 10. Graph of the Primary and Secondary Currents, with the Secondary Circuit Closed While the Primary Circuit is First Closed, Then Opened, and Reversed

The expressions in Table II are for the simplest ideal cases, where the constants of the primary and secondary circuits respectively are alone involved and L is taken constant as for a coil without iron core.

When both rise and fall of current in a given winding is required, the exponential expression contains two terms.

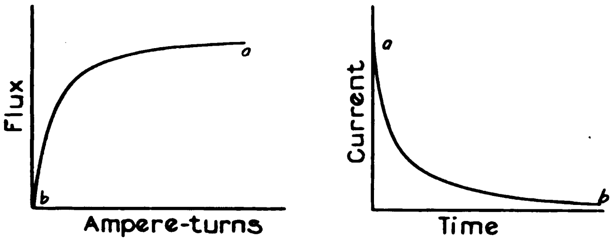
Closing, Opening, and Reversing the Primary Circuit

It is necessary to distinguish between the ideal mathematical relations and the actual physical action.

At first thought, it might seem that the secondary current impulse would be the same for either rise or fall of primary current, or that it might be doubled by reversing the primary.

It has been stated, and will be shown mathematically, that the secondary current is theoretically twice as much on opening as on closing the primary circuit. In addition, the rise in the primary is retarded by the inductance and regulation of the entire supply circuit, and in practice the secondary current impulse on closing the primary is small and may be of the order of two per cent of that on opening.

On breaking the primary circuit, the secondary current depends only on the constants of the secondary and the magnitude of the flux; but a quick, clean break is required, otherwise much of the energy (which is limited) goes to form an arc at the switch, and the maximum of the secondary current is reduced because this current is directly proportional to the rate of fall of the primary current.



Core Saturation Curve   Current Decay

Fig. 11. Method of Using the Saturation Curve to Approximate the Decay of the Secondary Current

TABLE II

SECONDARY OPEN. PRIMARY EXCITED. LOGARITHMIC RISE IN PRIMARY	SECONDARY CLOSED. PRIMARY OPENED. LOGARITHMIC FALL IN SECONDARY
The applied voltage equals the resistance drop, plus the inductive drop	
$E=I_1 R_1+L_1\frac{dI}{dt}=I_0R_1$	$0=I_2 R_2+L_2\frac{dI_2}{dt}$
$R_1(I_0-I_1)=L_1\frac{dI_1}{dt}$	$I_2 R_2=-L_2\frac{dI_2}{dt}$
$\frac{R_1}{L_1}\int dt=\int\frac{dI_1}{I_0-I_1}$	$\frac{R_2}{L_2}\int dt=-\int\frac{dI_2}{I_2}$
Integrating	
$-\frac{R_1}{L_1}t=\log(I_0-I_1)+C$	$-\frac{R_2}{L_2}t=\log I_2+C$
When $t=0$ $I_1=0$	When $t=0$ $I_2=I_0$
$C=-\log I_0$	$C=-\log I_0$
$-\frac{R_1}{L_1}t=\log\frac{I_0-I_1}{I_0}$	$-\frac{R_2}{L_2}t=\log\frac{I_2}{I_0}$
$\epsilon^{-\frac{R_1}{L_1}t}=\frac{I_0-I_1}{I_0}$	$\epsilon^{-\frac{R_2}{L_2}t}=\frac{I_2}{I_0}$
$I_1=I_0\left\{1-\epsilon^{-\frac{R_1}{L_1}t}\right\}$	$I_2=I_0{}^{-\frac{R_2}{L_2}t}$

In an ordinary case the primary current requires perhaps one second to reach a maximum, and the secondary about 0.002 sec.

Instantaneous reversal of the primary would give the same maximum secondary current as breaking the primary followed by a second impulse in general less than the original value, as shown in Fig. 10. There are difficulties in making a quick reversal, and the gain is questionable.

Open *vs.* Closed Magnetic Circuit

The flux is maintained by the primary current, and when this ceases the current in the closed secondary rises instantly to a value representing nearly the same ampere-turns and then dies away logarithmically. Apparently the primary ampere-turns alone determine the maximum value of the secondary current. If it were true that the secondary current is independent of the flux, a transformer without iron and a small main flux would suffice. This construction has been tried and works fairly well, but has two limitations:

(1). The energy involved and represented by the main flux is very small, and may be insufficient to supply the losses and maintain a large current.

(2). The fall of the secondary current may be so rapid—of the order of 10,000,000 amp. per sec.—as to render it ineffective through the results of induced currents.

For full effect, the secondary current should be maintained near maximum for an appreciable time, say 0.01 sec. This requires a high inductance or a high ratio of flux to exciting ampere-turns. That is, L in the formula must be large if t is to be large. Of course, the secondary resistance should always be as small as possible.

A simple method of approximating the fall of secondary current is to draw the saturation curve of the core, then to rotate this and draw new axes with current and time as the coördinates. This operation is shown in Fig. 11.

The air gap of the magnet should be closed by an iron keeper, as this concentrates the flux in the poles and greatly reduces the magnetizing force necessary. although this may not hold in some instances.

PART *III:* ACTIONS IN THE PRIMARY AND SECONDARY CIRCUITS CONSIDERED SIMULTANEOUSLY

Because the magnetic flux is common to both the primary and secondary circuits, the actions in them are simultaneous and must be so considered in an actual transformer. An explanation will now be given of the design calculations involved, taking the flux as the independent variable since it is common to both circuits.

Secondary Current when Exciting Primary

With the secondary short-circuited, a direct current is applied to the primary. The secondary current impulse is to be calculated.

Let: The secondary be of one turn

N = Primary turns
ϕ = Flux
I = Current
R = Resistance

Subscript 1 refers to the primary, and 2 to the secondary. Then, in the secondary the voltage induced by a change of flux plus that absorbed by the resistance drop is equal to zero.

$$\frac{d\phi}{dt} + I_2 R_2 = 0 \qquad (3)$$

Assuming no saturation and no leakage, the main flux is proportional to the algebraic difference in ampere-turns in the two windings.

$$\phi = (N_1 I_1 + I_2) D \qquad (4)$$

where D is the proportionality factor.

Substituting Equation (3) in (4):

$$\phi = \left\{ N_1 I_1 - \frac{1}{R_2}\frac{d\phi}{dt} \right\} D \qquad (5)$$

Rearranging:

$$I_1 = \frac{\phi}{N_1 D} + \frac{1}{N_1 R_2}\frac{d\phi}{dt} \qquad (6)$$

The voltage E applied to the primary is opposed by the resistance drop and the induced voltage.

$$E = I_1 R_1 + N_1 \frac{d\phi}{dt} \qquad (7)$$

Substituting Equation (6) in (7):

$$E = \frac{\phi R_1}{N_1 D} + \left\{ \frac{R_1}{N_1 R_2} + N_1 \right\} \frac{d\phi}{dt} \qquad (8)$$

The final flux is proportional to the steady value of the primary current.

$$\phi_0 = D N_1 \frac{E}{R_1} \qquad (9)$$

Substituting and rearranging:

$$\frac{R_1}{N_1 D}\int dt = \left\{ \frac{R_1}{N_1 R_2} + N_1 \right\} \int \frac{d\phi}{\phi_0 - \phi} \qquad (10)$$

Integrating:

$$\frac{R_1 t}{N_1 D} = -\left\{ \frac{R_1}{N_1 R_2} + N_1 \right\} \log\,(\phi_0 - \phi) + C \qquad (11)$$

where C is the integration constant

When $t = 0$ and $\phi = 0$

$$C = \left\{ \frac{R_1}{N_1 R_2} + N_1 \right\} \log \phi_0$$

Let

$$\left(\frac{R_1 + N_1^2 R_2}{R_1 R_2} \right) D = G \qquad (12)$$

Then Equation (11) becomes:

$$-\frac{t}{G} = \log\left(\frac{\phi_0 - \phi}{\phi_0} \right) \qquad (13)$$

Writing in other forms:

$$\epsilon^{-\frac{t}{G}} = \frac{\phi_0 - \phi}{\phi_0}$$

$$\phi = \phi_0\left(1 - \epsilon^{-\frac{t}{G}} \right) \qquad (14)$$

The secondary current may be determined by rearranging Equation (3) and substituting in Equation (14).

$$I_2 = \frac{1}{R_2}\frac{d\phi}{dt}$$

$$= \frac{1}{R_2}\frac{\phi_0}{G}\epsilon^{-\frac{t}{G}} \qquad (15)$$

$$= \frac{E N_1}{R_1 + R_2 N_1^2}\epsilon^{-\frac{t}{G}} \qquad (16)$$

If the ratio of turns is unity, and the primary and secondary resistances are equal, then, since the inductance

$$L_1 = D N_1^2 \qquad (17)$$

$$I_2 = \frac{E}{2 R_2}\epsilon^{-\frac{R_2}{2 L_1}t} \qquad (18)$$

The peak of the secondary impulse is thus numerically one-half the final primary ampere-turns if the primary and secondary losses are equal. The less the secondary resistance, the nearer will the secondary impulse peak approach the value of the steady primary ampere-turns.

These equations assume zero leakage flux, but apply closely to transformers of normal design. The inclusion of the leakage flux greatly complicates the calculations. In a well-designed transformer, the effect of the leakage flux is negligible.

When the primary circuit is closed, the peak of the secondary impulse is approximately the applied voltage divided by the combined resistances of both primary and secondary, all referred to the secondary.

The peak of the impulse when the primary circuit is broken is approximately equal to the primary current referred to the secondary.

The impulse peak, in closing the circuit, is less than in opening it by the ratio of the primary resistance to the total resistance all referred to the same winding.

Although the peak value is less when closing the circuit, the current dies out more slowly. Assuming no leakage and that the primary and secondary resistances are equal, the exponentials in Equation (18) are:

Closing...... $-\frac{R_2}{2\,L_2}t$

Opening...... $-\frac{R_2}{L_2}t$

The magnetizing effect depends on both the intensity and the duration of the impulse. For transformers with open magnetic circuits or small cores (small fluxes), the maximum value of the transient may be two to four times the continuous current value for equal magnetizing effect.

Breaking the primary circuit of a transformer with a large flux appears to be the most effective method and this is indicated by tests.

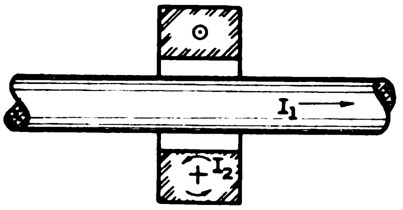


Fig. 12. Diagram Showing the Directional Relation of the Current and the Induced Current in the Magnetizing Magnet

The results with the open magnetic circuit transformer and magnet of Fig. 1 were determined by both methods.

Excitation	6000 amp.-turns
Relative flux	closing = 50
Relative flux	opening = 124

Transformer Leakage Flux

The maximum value of the secondary current impulse is directly proportional to the flux linked with it, therefore it is affected by the leakage flux, or depends on the coupling coefficient. This coefficient is defined as:

$$K = \sqrt{\frac{M^2}{L_1\,L_2}}$$

where M = mutual inductance
L_1 = primary inductance
L_2 = secondary inductance.

The maximum value of the current impulse equals K times the primary ampere-turns if no energy is lost in the arc at the switch.

Time of Opening Primary Circuit

The primary circuit must be broken quickly. If the primary were opened slowly by moving a rheostat, no appreciable impulse would be induced in the secondary. Actually, if there is delay in opening the circuit, an arc will form at the switch and will absorb most of the energy of the magnetic field.

Consider a transformer with a short-circuited secondary and with a steady current I_0 flowing in the primary. Let the primary current decrease linearly in time T, which is a valid assumption:

$$I_1 = I_0 \frac{(T-t)}{T} \qquad (19)$$

The voltage equation for the secondary circuit is:

$$I_2\,R_2 + L_2\,\frac{dI_2}{dt} + M\,\frac{dI_1}{dt} = 0 \qquad (20)$$

where M is the mutual inductance.

Differentiating Equation (19) and substituting in Equation (20):

$$dI_2 + \left(\frac{I_2\,R_2}{L_2} - \frac{M\,I_0}{L_2\,T}\right) dt = 0 \qquad (21)$$

This is a lineal differential equation and its solution is

$$I_2 = -\frac{M\,I_0}{R_2\,T}\left\{1 - \epsilon^{-\frac{R_2}{L_2}t}\right\} \qquad (22)$$

This applies from time $t=0$ to time $t=T$.

After this the current dies out according to Equation (2).

To see the real meaning, substitute numerical values. Let $\frac{M\,I_2}{R_2} = 10{,}000$ and $\frac{R_2}{L_2} = 1.0$. The following tabulation gives the maximum value of the secondary impulse for various values of T which is the time required for the primary current to go from the steady value to zero:

T	Amp. (Max.)
1.0 sec.	6321
0.5	7870
0.2	9065
0.05	9760
0.02	9900

Minimum Time for Magnetization

The minimum time required for application of the magnetizing force to effect complete saturation of the magnet seems to be undetermined. Since radiofrequency transformers with iron cores operate successfully at 1,500,000 cycles, the minimum time must be extremely short and possibly of the order of the time for orbital revolution of electrons.

The limitation is thus not in the crystal, atom, nor electron, but in the demagnetizing effect of secondary currents induced in the magnet itself, which are always in a direction to oppose the cause. The effect is indicated in Fig. 12.

The time it is necessary to maintain the current impulse above that required to saturate the steel depends on the size and form of the magnet, since this determines the stray (demagnetizing) current.

Repeated Impulses

Repeated impulses have little effect on a magnet excited to saturation by the first impulse. In general a slight increase in strength is produced by a second impulse, although the first appears to be far beyond saturation.

The following table gives the results observed in three actual cases, using the open magnetic circuit transformers and magnet illustrated in Fig. 1:

Amp.-turns in Primary	Impulses	Relative Flux
19,200	1	177.9 (saturated)
"	5	179.7
4,500	1	46
"	5	117
"	10	126
20,000	1	115.1
"	2	117.2
10,000 continuous	1	116.7

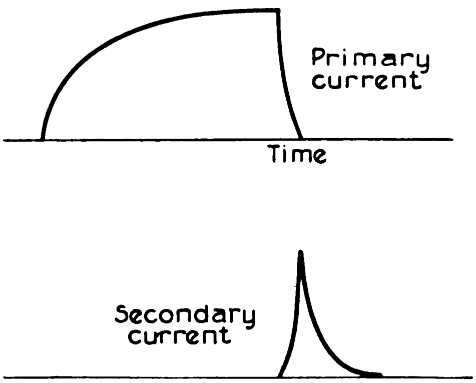


Fig. 13. Graph of Primary and Secondary Currents in a Transformer Having a Small Saturated Core. The primary circuit is made and interrupted while the secondary circuit remains short-circuited

The three groups in the table are not directly comparable with each other.

If several magnets are excited at the same time from a single impulse, the available energy must be divided between them. Since the total energy is small, its division among several magnets will mean that the total for any one is less.

Amp.-turns in Primary	Number of Magnets	Relative Flux
19,200	1	177.9 (saturated)
"	4	160.4

Recapitulation

(1). Maximum secondary current is produced by the instantaneous break of primary current.

(2). Primary and secondary ampere-turns are nearly equal.

(3). Energy of secondary current depends on total flux and density (equals the volume times the square of the density).

(4). Time of decrease of secondary current depends on permeance of magnetic circuit. That is, it is inversely proportioned to the inductance L.

(5). Energy and time must not be too small for practical effects. This means that the transformer should have an iron core of large cross-section worked below saturation.

(6). Rise of primary current is relatively slow. Rise and fall of secondary current is almost instantaneous.

(7). *Maximum secondary current* is proportional to primary ampere-turns, or to length of magnetic circuit, the flux being constant. *Time secondary current is maintained* varies with permeance of magnetic circuit, or the cross-section, other things being equal.

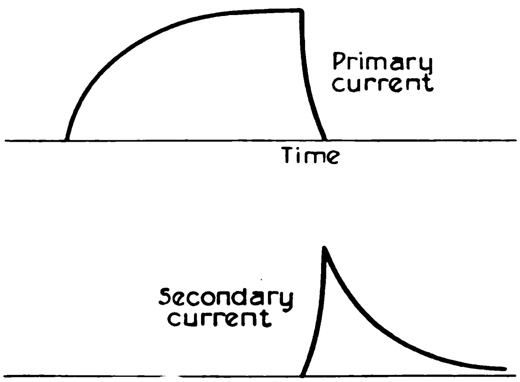


Fig. 14. The Influence of a Large Unsaturated Core on the Duration of Secondary Current Flow. Compare with the otherwise identical Fig. 13

(8). Primary voltage, current, and resistance are interdependent, and the constants of the transformer vary with the proportions of the core and winding.

(9). Because of effect of self-induction and stray currents, a high instantaneous current may be less effective than a lower current maintained for a longer time.

(10). Rise and fall of current in primary and secondary are about as indicated in Fig. 10. This shows the futility of utilizing the secondary current produced by closing or reversing the primary.

(11). The effect with a small saturated core is indicated in Fig. 13.

(12). The effect with a large unsaturated core is indicated in Fig. 14.

(13). The variation of current is at a rate proportional to itself (logarithmic) and is given by an expression whose general form is $I = \dfrac{I_0}{\epsilon^{\frac{R}{L}t}}$.

A Set of Curves for Skin Effect in Isolated Tubular Conductors

By A. W. EWAN
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THE name "skin effect" has been given to that phenomenon whereby, when alternating current flows in an isolated conductor, the greater part of the current will be found in the region adjacent to the surface of the conductor. The cause, briefly, is this: Because of the magnetic field inside of and surrounding the conductor, there is produced within the latter a voltage of induction which is larger toward the centre than at the surface. As the vector sum of the voltage of induction and the IR drop must be the same, per unit length, for each filament of the conductor, the IR drop along an inside filament is less than that along one at the surface. The actual resistance of each filament, however, must be the same in each case. This results in a higher current density at the surface than at the centre, and because of the consequent incomplete utilization of the available cross-section, an alternating-current resistance which is greater than the resistance of the same conductor to direct current.

In connection with the manufacture and use of tubular conductors such as hollow or cored cables for overhead or underground electric power transmission, it is necessary to know the values of the a-c. resistance. This is true also in any class of work such as electric furnace operation, where currents of large magnitude are carried by tubular conductors. Tubular conductors are used also in radio work, for carrying currents of high frequency.

Tubular conductors of usual design have an increase in resistance of less than about 20 per cent at the frequency of the current used. The curves of skin effect of isolated tubular conductors which have been published hitherto, have been drawn for rather large increases in resistance, and there has been a demand for some time for a set of curves which would give accurate readings in the useful range of less than 20 per cent increase. Accordingly, the set of curves given in Fig. 1 has been calculated and drawn up. To determine the a-c. resistance without resort to curves requires computations of some length, and makes necessary the employment of a table of Bessel functions.

The curves of Fig. 1 cover the range from a solid round wire to an infinitely thin tube. In their calculation three types of problems are encountered. These are:

(1). That of a solid wire
(2). That of a tube of finite thickness of wall
(3). That of the limiting case of an infinitely thin tube of finite resistance.

Although all three are related, yet each case requires a more or less distinct method of calculation.

The problem of skin effect in a solid wire was solved by Maxwell,(1) and published by him in *Electricity and Magnetism*. The result is often given in the following form:

$$\frac{R'}{R}=\frac{mr}{2}\;\frac{\text{ber}\,mr\;\text{bei}'\,mr-\text{ber}'\,mr\;\text{bei}\,mr}{\text{ber}'^2\,mr+\text{bei}'^2\,mr}$$

where

r = radius of wire in centimeters

$m=\sqrt{\dfrac{4\,\pi\,\mu\,\omega}{\rho}}=2\pi f$

f = frequency in cycles per second

μ = permeability of the material of the wire, assumed constant

ρ = resistivity of the wire in abohms per cm. cube

$\dfrac{R'}{R}$ = the resistance ratio, *i.e.*, the ratio of the alternating-current resistance to the direct-current resistance of the wire.

Ber and bei indicate respectively the real and the imaginary parts of Bessel functions of the first kind and order zero.(2) The primes with the Bessel functions denote the first derivatives.

Using this formula, and others derived from it, E. B. Rosa and F. W. Grover(3) have computed a table of the resistance ratio for non-magnetic wire.

For the curve $t/d=0.5$, the various points were not recomputed, but the necessary values were taken from this table.

The expression for the magnitude of the skin effect in a tubular conductor of circular section was first obtained by Oliver Heaviside.(4) He gives the solution for the a-c. impedance in terms of Bessel functions.

The formula may be written as follows:

$$\frac{Z'}{R}=\frac{\text{j}\,m\,r}{2}\;\frac{(r^2-q^2)}{r^2}\;\frac{\text{ber}\,mr+\text{j}\;\text{bei}\,mr+\dfrac{C+\text{j}\,D}{A+\text{j}\,B}\,(\text{ker}\,mr+\text{j}\;\text{kei}\,mr)}{\text{ber}'\,mr+\text{j}\;\text{bei}'\,mr+\dfrac{C+\text{j}\,D}{A+\text{j}\,B}\,(\text{ker}'\,mr+\text{j}\;\text{kei}'\,mr)}$$

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(1) J. Clerk Maxwell: *Electricity and Magnetism*, 1873, Vol. II, paragraph 689.

(2) "Bessel Functions for A-c. Problems," by H. B. Dwight, *Trans. A.I.E.E.*, July, 1929, p. 812, Table I.

(3) *Scientific Paper No. 169 of the Bureau of Standards, Washington, D.C.*, by E. B. Rosa and F. W. Grover, Table XXII.

(4) Oliver Heaviside: *Electrical Papers*, Vol. II, p. 67, Copley Publishers, Boston (Mass.).

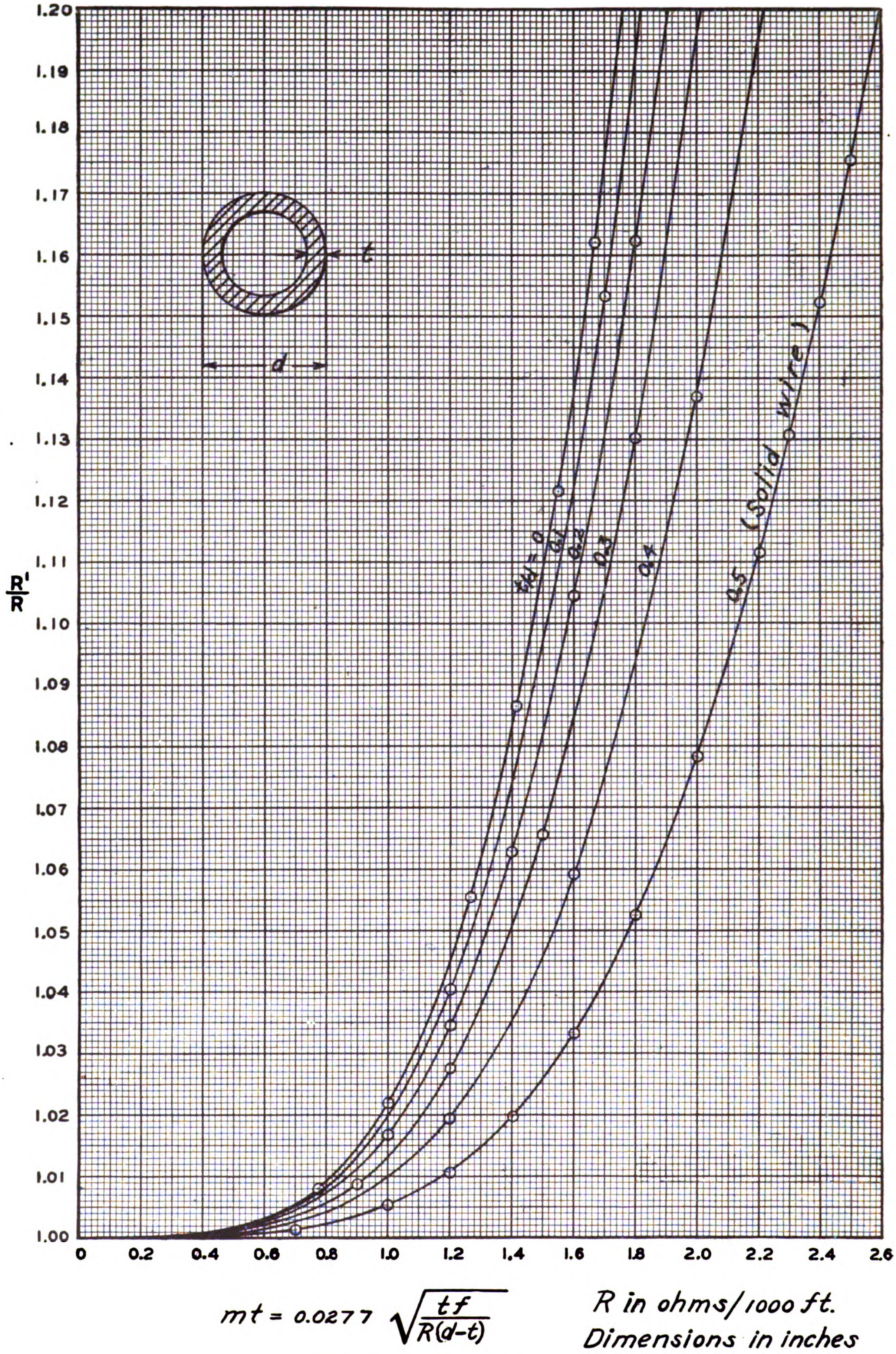

Fig. 1. Skin Effect Ratio of Isolated Tubes

where

$\frac{Z'}{R}$ = ratio of the a-c. impedance of the tube to the d-c. resistance

r = outside radius of the tube in centimeters

q = inside radius of the tube in centimeters

$j = \sqrt{-1}$

$$\frac{C + j\,D}{A + j\,B} = -\frac{\text{ber}'\,mq + j\,\text{bei}'\,mq}{\text{ker}'\,mq + j\,\text{kei}'\,mq}$$

Ker and kei indicate respectively the real and the imaginary parts of Bessel functions of the second kind and order zero.(2) The primes with the Bessel functions denote the first derivatives.

This expression of Heaviside's is used in the present calculation for tubes with values of $t/d = 0.1, 0.2, 0.3,$ and 0.4. After solving the expression for an actual case, the answer will be found to consist of two numbers, one real and the other imaginary. The real number is the desired resistance ratio. The second number gives the change in inductance of the tube with change in frequency.

For the curve $t/d = 0$, the expression just given cannot be used, as an attempt to solve for this case results in indeterminate values of mr and mq. Evidently another method must be used. The formula used is as follows:

$$\frac{Z'}{R} = \frac{1 + \frac{j\,m^2t^2}{2!} + \frac{(j\,m^2t^2)^2}{4!} + \cdots}{1 + \frac{j\,m^2t^2}{3!} + \frac{(j\,m^2t^2)^2}{5!} + \cdots}$$

This is sometimes expressed as a hyperbolic function of a complex quantity.

In plotting the curves, the same plan was used as for previous instances.(5) A square root sign is contained in the expression for mt, but this was allowed to remain as it gives a closer spacing of the curves, making interpolation easier. Although the absolute system involving metric units of measurement must be used in connection with the formulas, English units are to be employed in the expression for mt found in Fig. 1, as noted thereon. The change, which accounts for the constant, is made for convenience.

The curves are calculated for solid conductors and so, theoretically, are not for stranded cables. Experiments show, however, that for the range dealt with in this paper, the difference in a-c. resistance between a solid conductor and a stranded one of the same d-c. resistance is negligible. This has already been pointed out elsewhere(6) and is plainly indicated by a graph showing that if $\sqrt{\frac{f}{R_{dc}}}$ is less than 95, the increase in resistance of a cable due to stranding and spiraling is practically negligible. It is also shown that if $\sqrt{\frac{f}{R_{dc}}}$ is less than 95, then R'/R is less than 1.20, which is the range dealt with in the present treatment.

It is to be noted particularly that if the curves are applied to stranded cables, the value of mt is not to be found from the formula involving ρ, but the formula involving R given in Fig. 1 should be used.

The curves and calculations in this article apply to isolated conductors, as has been indicated. For a general rule as to whether the increase in resistance due to the proximity of other current-carrying conductors will be appreciable,(6) it may be said that when two round conductors are carrying equal alternating currents at an axial distance apart of four or more times the diameter of the first conductor, the proximity of the second conductor does not increase the a-c. loss of the first by more than four per cent, regardless of how high the frequency may be.

The work of preparing the curves here presented was done in connection with a thesis at Massachusetts Institute of Technology, under the supervision of Dr. H. B. Dwight.

Example: Given a conductor of the following dimensions and constants, to find its a-c. resistance at a frequency of 60 cycles:

Outside diameter, $d = 1.3$ in.
Inside diameter, $2q = 0.52$ in.
D-c. resistance = 0.0073 ohm per 1,000 ft.

Then

$$t = \frac{d}{2} - q$$

$$= \frac{1.3}{2} - 0.26$$

$$t = 0.39 \text{ in.}$$

$$\frac{t}{d} = \frac{0.39}{1.3} = 0.30$$

$$(d - t) = 0.91 \text{ in.}$$

$$m\,t = 0.0277\sqrt{\frac{t\,f}{(d-t)\,R}}$$

$$= 0.0277\sqrt{\frac{(0.39)\;60}{(0.91)\;(0.0073)}}$$

$$m\,t = 1.642$$

On curve $t/d = 0.3$ at $mt = 1.642$, $\frac{R'}{R} = 1.093$

$R' = 0.0073\ (1.093) = 0.0080$ ohm, the a-c. resistance at 60 cycles.

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(5) "Skin Effect in Tubular and Flat Conductors," by H. B. Dwight, *Trans. A.I.E.E.*, 1918, p. 1379, Fig. 3.

(6) "Skin Effect and Proximity Effect in Tubular Conductors," by H. B. Dwight, *Trans. A.I.E.E.*, 1922, p. 189, Fig. 2.

Advantages of Metal-clad Switchgear

By G. H. KOHN

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General Electric Company**

CENTRAL station companies, whose problem is to provide electric service to important communities and all branches of industry, have long realized the necessity of safe, reliable, switching equipment. Metal-clad switchgear, the latest type of metal-enclosed switching equipment, with its characteristic design and simplicity in operation, solves this problem. This is indicated by a marked increase in demand since its introduction in this country a few years ago.

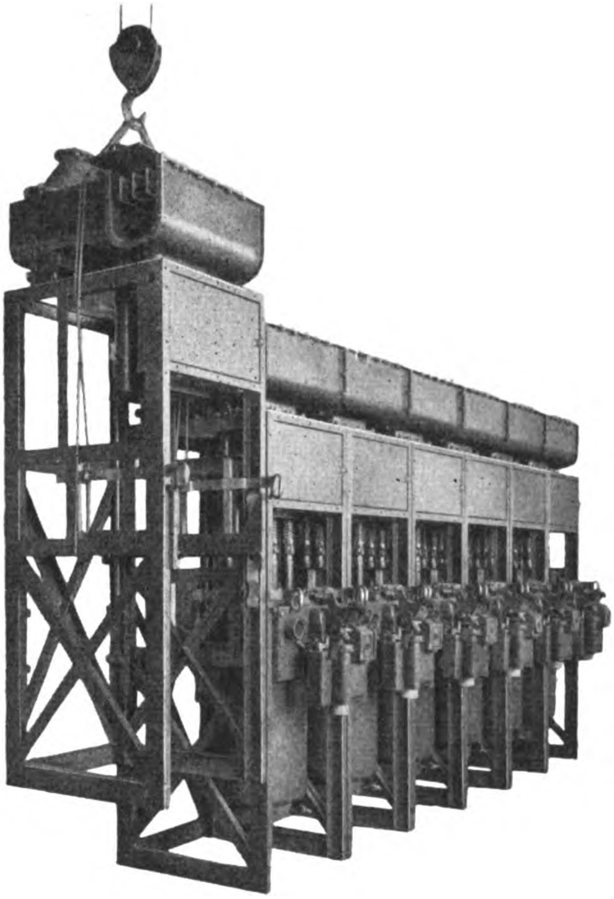


Fig. 1. Metal-clad Switchgear, Showing Method of Installing an Additional Unit

Early attempts to obtain safety and service reliability resulted in cell structures with main, auxiliary, and transfer buses, selector and by-pass disconnecting switches, instrument transformers and oil circuit breakers installed in individual masonry compartments. This accomplishes certain results, but not with the same safety of operation and maintenance as can be obtained with metal-clad equipment.

The outstanding advantage of metal-clad switchgear is safety. This is exhibited in two classes, *viz.*, that afforded the personnel, and safety to the system. Other advantages are greater service reliability, field labor reduced to a minimum since units are built complete at the place of manufacture, easily removable oil circuit breaker elements, decreased floor space, and decreased maintenance expense.

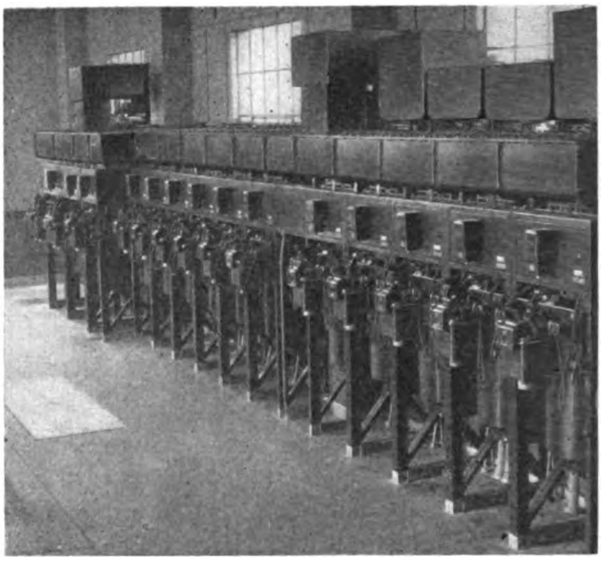


Fig. 2. Typical Installation of Indoor Metal-clad Switchgear

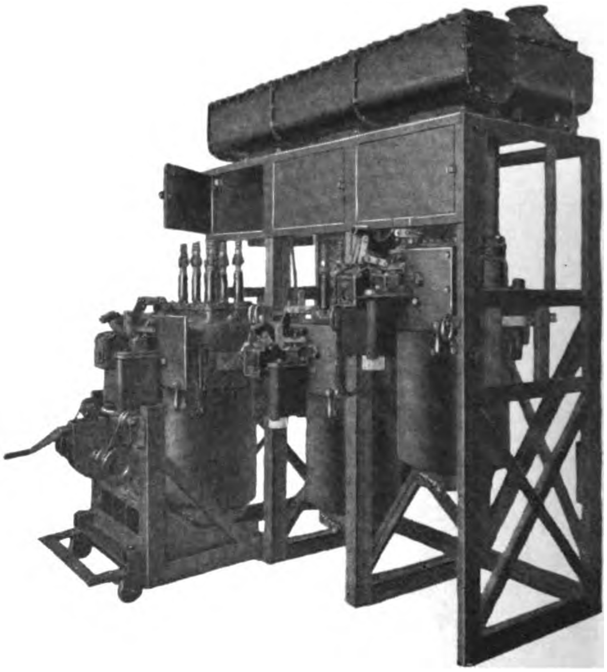


Fig. 3. View Showing (at left) a Unit Removed on an Installing Truck, (in center) a Unit in the Disconnected or Testing Position, and (at right) a Unit in the Normal Operating Position

Positive interlocks prevent the insertion or removal of the oil circuit breaker element unless the breaker is open. The design is also such that the breaker tank cannot be removed while in the operating position.

The removable element may be padlocked in the disconnected or test position, thereby permitting remote repairs to machines, cables, etc., in safety. The buses and current and potential transformers are installed in separate compartments surrounded with grounded metal. Service interruptions due to mistakes in operation of isolating disconnecting switches, accidental contact of live parts with foreign objects, or due to rodents are eliminated. Internal faults are localized and are not directly communicated to adjacent circuits or apparatus.

The fact that metal-clad equipments are built as nearly complete as possible at the factory results in decreased time and expense for erection and installation, elimination of detail design and engineering on the part of the operating company, decreased maintenance expense, and a material increase in salvage value when system changes necessitate relocation or replacement of existing apparatus.

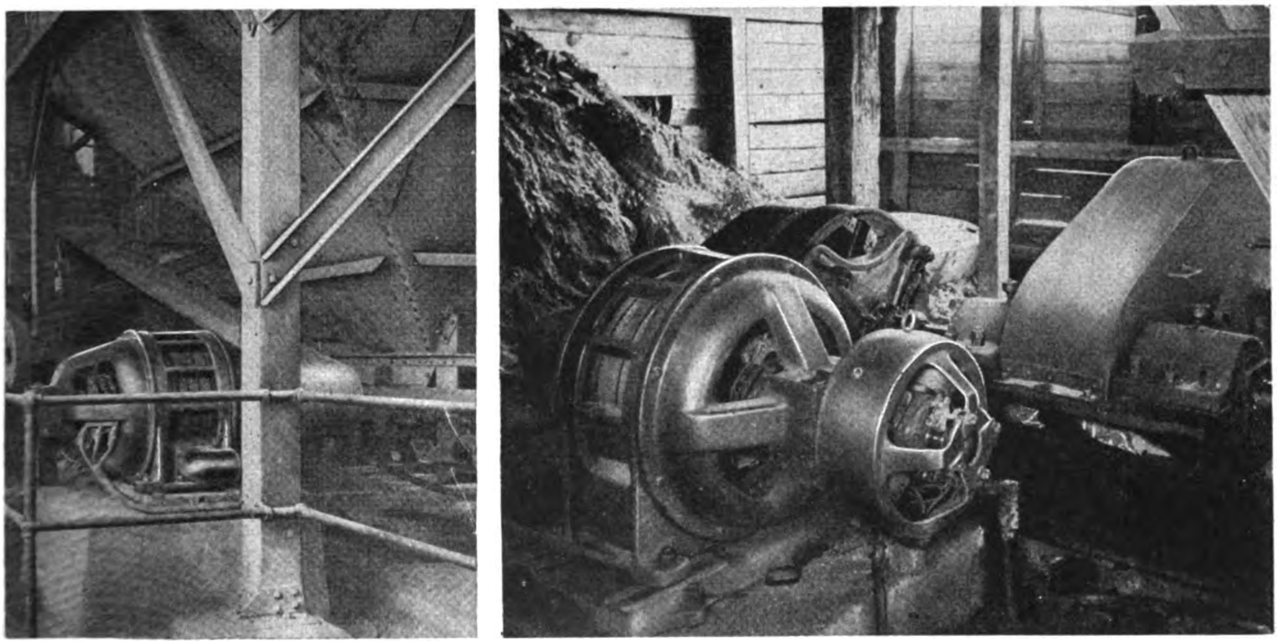
Maintenance is reduced to periodic inspection of the oil circuit breaker and its operating mechanism. Removable elements of the same capacity are made interchangeable, and service interruptions are limited to the short period required for removing and replacing a unit with a spare or inactive one. This feature will eliminate the necessity for a more elaborate switching scheme in a number of cases where the fixed oil circuit breaker was formerly used.

Removing the oil circuit breaker vertically in this class of switchgear decreases the required floor space to a minimum and results in a saving in building costs. A disconnected position is provided in each unit so that the oil circuit breaker may be lowered to a position where the main connections are separated by automatic disconnecting devices acting as interlocked isolating switches. In this position the oil circuit breaker may be operated and tested either electrically or manually. At any point between the normal operating and test positions, the oil circuit breaker is both electrically and mechanically inoperative.

A portable elevating truck serves to remove or replace an oil circuit breaker element. An inspection rack placed in any desired location facilitates servicing the oil circuit breaker in safety, away from high-voltage parts, at the attendants' convenience. The control wiring may be run to the inspection rack, permitting electrical operation and testing of the oil circuit breaker from the normal operating source.

Little or no differential in cost is required to justify moderate-capacity metal-clad switchgear. The manufacturer's cost is obviously higher than that for equivalent masonry-cell-mounted equipment. However, the value of floor space must be considered as well as the cost of detail engineering and drawings on the part of the operating company and the installation cost of the masonry structure. The added safety to human life and to the system, the high salvage value, and the decreased maintenance expense make metal-clad switchgear most attractive. It represents the highest degree of advance in the art of switchgear design today.

Motors in the Clay Products Industry



On the left is a 75-hp. Wound-rotor Induction Motor driving a crusher; on the right, a 75-hp. Synchronous Motor driving a granulator

Traveling Waves on Transmission Lines

Tests with Artificial Lightning Surges

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(A paper presented at the Winter A.I.E.E. Convention in New York City, January 27-31, 1930)

IN May, 1929, a joint investigation, having for its object the securing of information which will serve to give definite figures for the various effects which take place when overhead circuits are subjected to traveling waves such as those caused by lightning, was begun by the General Electric Company and the Consumers Power Company. During the previous summer a certain amount of preliminary work was done, using a portable impulse generator having an open-circuit potential of 400 kv. on a 66-kv. circuit of the Turners Falls Power and Electric Company.(1) This work was continued the summer of 1929 and some of the data obtained, particularly on attenuation, will be found in this article. Other data dealing with choke coils have been published recently.(2)

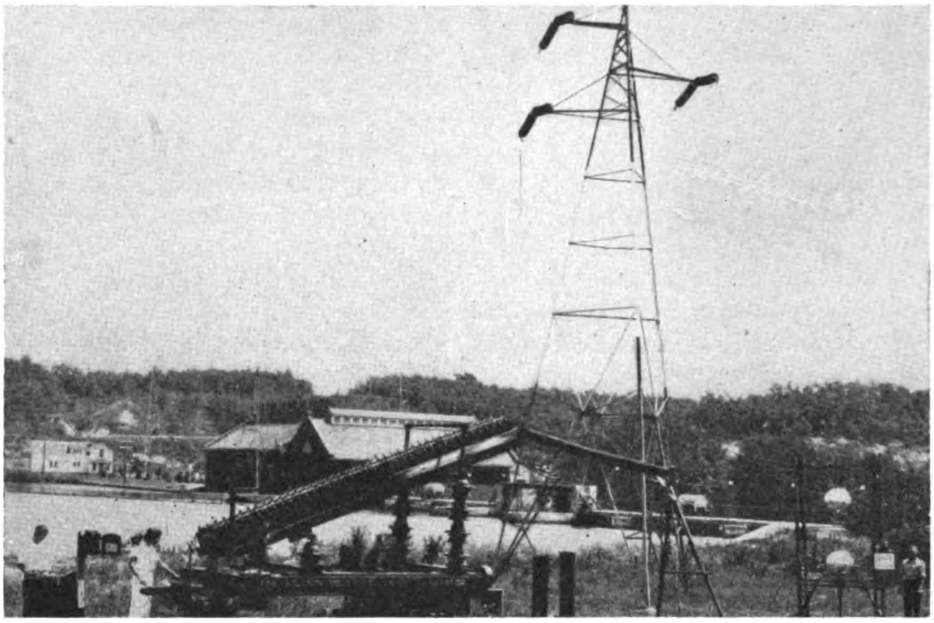

Fig. 1. The Million-volt Impulse Generator Set Up for Tests

The historic S-19 transmission line of the Consumers Power Company between Croton Dam and Grand Rapids, which was the first line to transmit electrical energy at 110,000 volts, was set aside for the study of transients produced artificially. At Croton Dam an outdoor laboratory, housing a cathode-ray oscillograph, was erected for the purpose of securing records of natural lightning on the T-20 line.(3) Results of an investigation with surge voltage recorders on the Consumers system have already been published.(4) In making the study on the S-19 line, the cathode-ray oscillograph was available for determining the wave form of impulses at the laboratory end of the line.

The impulse generator used in these tests was a portable million-volt equipment(5) consisting of 40 banks of capacitors, each bank having a capacity of 0.50 μ f. The banks are charged in parallel to 25 kv. and discharged in series as is done in the Marx circuit.(6) The connections are so arranged that the polarity of the generator may be changed at will, which is necessary for the type of tests to be described. The power requirements for the impulse generator are such that it may be operated from a 110-volt lighting circuit. Fig. 1 shows the million-volt generator set for test at Croton Dam.

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(1) "Cathode-ray Oscillograph Study of Lightning Surges on the Turners Falls Transmission Lines," by K. B. McEachron and V. E. Goodwin, *A.I.E.E. Trans.*, Vol. 48, July, 1929, p. 953.

"Reflection of Transmission Line Surges at a Terminal Impedance," by O. Brune, GENERAL ELECTRIC REVIEW, Vol. 32, May, 1929, p. 258.

(2) "Cathode-ray Oscillograph Study of the Operation of Choke Coils on Transmission Lines," by K. B. McEachron, GENERAL ELECTRIC REVIEW, Vol. 32, December, 1929, p. 668.

(3) "Lightning Voltage on Transmission Lines," by R. H. George and J. R. Eaton, presented at the A.I.E.E. Winter Convention, 1930.

(4) "Surge Investigation on the 140-kv. System of the Consumers Power Company During 1927," by J. G. Hemstreet and J. R. Eaton, *A.I.E.E. Trans.*, Vol. 47, 1928, p. 1125.

(5) "The Portable Impulse Generator," by E J. Wade, GENERAL ELECTRIC REVIEW, Vol. 33, March, 1930, p. 180.

(6) "Erzeugung von verschiedenen Hochspannungs, arten zu Versuchs-und Prüfzwecken," by Erwin Marx, *Elektrotech. Zeitsch.*, 1925, p. 1298.

The S-19 line is approximately 45 mi. in length and is not paralleled by any other lines except for a short distance near Grand Rapids. It is of three-legged steel tower construction, the steel being set in the earth with concrete footings somewhat similar to the present Malone anchors. The conductors are 72,670 circular-mil seven-strand copper, insulated with seven insulators spaced 4¾ in. The line does not have a ground wire, nor are the conductors transposed. Fig. 2 shows a typical tower construction.

The cathode-ray oscillograph for recording lightning surges is installed on the T-20 line about 1000 ft. from the Croton Dam generating station and the S-19 line was extended to this point, four additional towers being required. The impulse generator was set up one span away from the oscillograph and the line provided with jumpers at this point, so that the impulse could be sent either to the oscillograph for checking the open-circuit wave, or out on the line. It was also possible to connect with the T-20 line and this was done for the purpose of checking the calibration of the cathode-ray oscillograph on this line. (3)

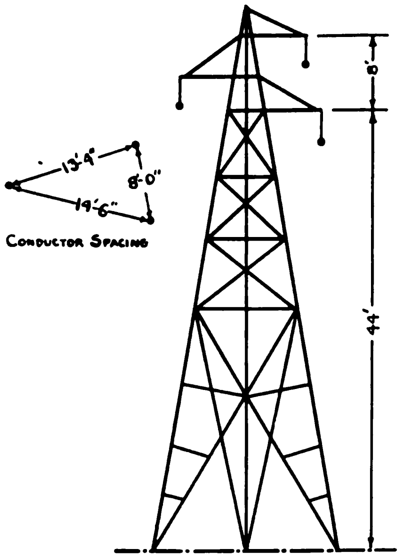

Fig. 2. Typical Three-post Tower, Showing the Arrangement of Conductors

Most of the measurements given in this article were made with sphere gaps which were moved along the line by truck, communication being maintained with the impulse generator and oscillograph stations by tapping local telephone lines.

Attenuation

The problem of attenuation of surges on transmission lines is important from the operating standpoint as well as being of great importance from a purely scientific point of view. Knowledge of attenuation makes it possible to determine the distance that surges can travel and still be dangerous to connected apparatus. In this article attenuation will be understood to refer to the decrease in crest surge voltage without regard to change of wave shape.

Corona loss (7) is now generally regarded as one of the most important factors affecting attenuation. Some attempts have been made to deduce the rate of attenuation of surges from the constants in the known empirical formulas for corona loss on lines at power-frequency voltages. It is extremely improbable, however, that the final state of breakdown of the air occurring at these frequencies is reached in the duration of the lightning surge, especially if its time above the corona voltage is short, as in the case of an insulator flashover on or near the front of the wave. Without entering into any extended theory of attenuation, a brief consideration of the more important factors will be given.

Effects of Parallel Conductors

The formation of corona around a conductor occurs when the potential gradient in this space exceeds a value known as the critical corona voltage. This gradient is very nearly proportional to the charge on the conductor. At a given potential the charge is proportional to the electrostatic capacity of the conductor to the earth. The electrostatic capacity of the conductor to earth is affected by the presence of other charged conductors nearby, being increased when the other conductors are charged to the opposite sign and decreased when they are charged to the same sign.

When a surge is traveling on a number of conductors in parallel, as is always the case on an actual transmission line, the capacity to earth is reduced by the presence of surges of the same sign on the other conductors. Thus the charge on each conductor at a given surge voltage is less; so the potential gradient and consequently the corona is less on each conductor than would be the case with a single conductor. Following out this line of reasoning one would expect to find the attenuation less when several conductors in parallel were carrying the same surge. The tests made show conclusively that increasing the number of conductors in parallel decreases the attenuation.

Effect of Polarity

It is a well-known fact that there is a considerable difference in the appearance of positive and negative corona. (8) With dissimilar electrodes, as in a pin-type insulator, flashover will take place at a lower potential when the cap is positive than when negative, although as the rate of potential application is increased the positive and negative spark potentials approach a common value. (9) Thus one would expect that a difference would exist in the corona loss for positive and negative impulses and that in general the loss for the positive impulse would be greater. On this basis, the attenuation with negative impulse should be less than for the positive impulse, which was in general found to be true. Since, however, the insulator tests referred to showed that as the time to breakdown became less the difference between positive and negative impulses disappeared, it is reasonable to expect that with extremely short waves positive and negative attenuation would be equal. The only tests made with a short wave were made with a chopped wave having a seven-microsecond front, which was probably much too long to give equal values of attenuation for positive and negative surges.

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(7) "Surge Voltage Investigation on Transmission Lines," by W. W. Lewis, *A.I.E.E. Trans.*, Vol. 47, 1928, p. 1111.

(8) "The Law of Corona and the Dielectric Strength of Air—II," by F. W. Peek, Jr., *A.I.E.E. Trans.*, Vol. 31, 1912, p. 1051.

(9) "Time Lag of Insulators," by E. J. Wade and G. S. Smith, *Electrical World*, Aug. 18, 1928, p. 309.

Effect of Length of Waves

The state of breakdown of the air in the corona area around a conductor is changing very rapidly during the passage of a surge, and consequently the attenuation varies on different parts of the surge. This would affect the attenuation of surges, the amount depending upon the wave shape. Thus if the corona loss[10] were greatest during the initial stages of breakdown, a short wave would suffer more attenuation than a long wave. The tests made have shown that attenuation is dependent on wave shape.

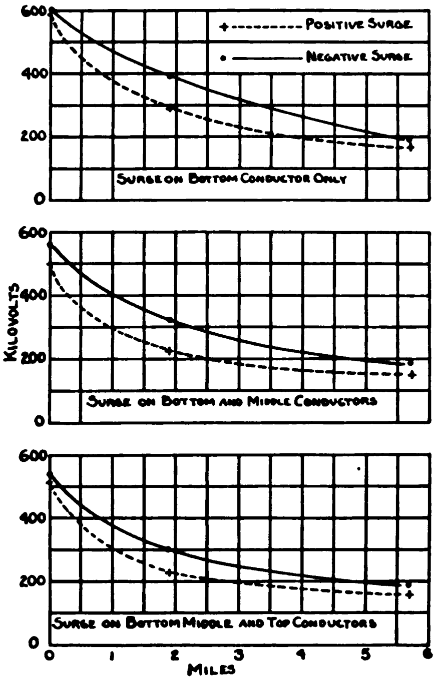

Fig. 3. Attenuation with Steep Waves on One, Two, and Three Conductors

Effect of Ground Wire

With a traveling wave the ground wire takes up a charge of opposite sign to that of the wave in the line conductor and, as pointed out previously, this results in an increased charge on the line conductors which in turn results in an increased corona loss at a given potential. This effect tends to increase the attenuation. On the other hand, the increase in charge results in an increase of energy of the surge, which tends to decrease the attenuation. It has been assumed[11] that the resultant effect of the ground wire is to increase the attenuation; but the attenuation was found to be less with the ground wire, especially in the case of the negative impulse on the line conductor. Apparently the increases in surge energy and corona loss are more or less balanced in the positive impulse, but with the negative surge the increase in surge energy seems to be greater than the increase in corona loss, resulting in a decreased attenuation.

Test Results

The attenuation tests were made with three different wave forms: A fast wave reaching its crest in less than one microsecond; a slow wave reaching its crest in seven microseconds; and a chopped wave produced by cutting off the slow wave at its crest by the use of a parallel sphere-gap. These waves of both positive and negative polarity were applied to a single conductor and also to two and three conductors in parallel. As the S-19 line was not provided with a ground wire the influence of the ground wire on attenuation was studied by grounding the conductors at approximately half-mile intervals.

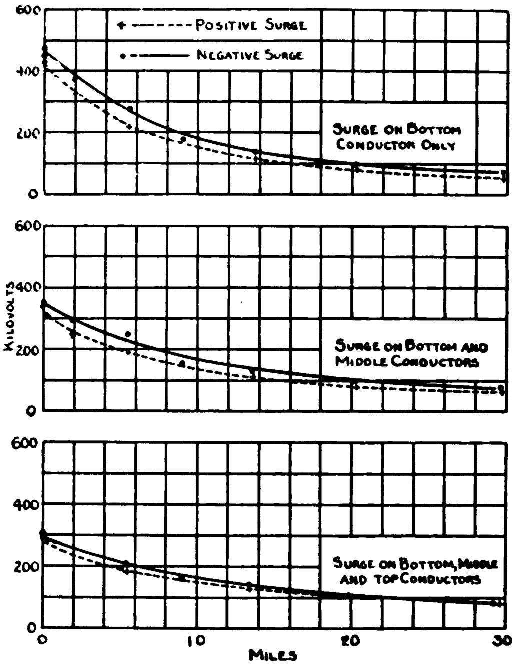

Fig. 4. Attenuation with Slow Waves on One, Two, and Three Conductors

In Fig. 3 are given curves showing the variation in measured crest voltage with distance along the line for both positive and negative steep waves applied to a single conductor and to two and three conductors connected in parallel at the impulse generator. The applied voltage decreases with the number of conductors in parallel because of the increased load on the surge generator due to the decreased surge impedance when several conductors are connected in parallel. The positive wave in each case shows more attenuation for potentials in excess of 200 kv. than does the negative.

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(10) "Streamer Currents in High Voltage Sparkover," by J. Slepian and J. J. Torok, *Electric Journal*, March, 1929.

(11) "Effect of Ground Wire on Traveling Waves," by J. H. Cox and J. Slepian, *Electric World*, Sept. 22, 1928.

The attenuation tests with the slow wave extended over a distance of 30 mi. from the impulse generator. The results are given in Fig. 4. These data cover both positive and negative impulses on one, two, and three conductors. The results with a single conductor show that the negative impulse has decreased from 475 kv. to 90 kv. and the positive from 415 kv. to 60 kv. as a result of traveling 30 mi. It is interesting to compare these results with those given by W. W. Lewis⁽⁷⁾ which were obtained from studies of surge records from lightning storms. Mr. Lewis gives a formula derived by Foust and Menger in which the voltage e at a point s miles from the point of inception is as follows:

$$e = \frac{e_o}{k\,s\,e_o + 1}$$

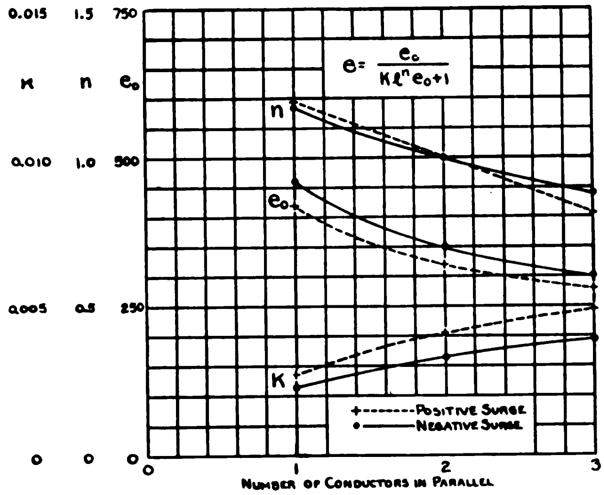

Fig. 5. Attenuation Constants for S-19 Line

where e_o is the voltage at the point of origin, and k a factor found empirically.

This equation fits the data given in Fig. 4 fairly well for the first ten miles, beyond which the loss due to corona becomes small. E. W. Boehne has suggested that the s in the equation be replaced by s^n which with the proper values for n checks the curves closely. In Fig. 5 are given the values for n and k for the various conditions of the test. The values of both n and k are dependent on many factors which the present investigation did not disclose. The values given apply only to the slow wave used and the particular line tested.

It is of interest to note that on the Turners Falls Line⁽¹⁾ a brief study of attenuation on a single conductor gave for n a value of 0.75 and for k a value of 0.00069 with an e_o of 230 kv. These values are quite different from those obtained on the S-19 line and indicate that the values of n and k must be determined for each individual condition considered.

The results of the tests made with the chopped slow wave are given in Fig. 6, which shows not only the decrease of the positive and negative surge with distance but also the potential on the free conductor where such existed. It is interesting to note that the change of potential of the free wire with distance is very small and approaches the potential of the conductors carrying the original surge. When the surge was applied to the bottom conductor, the top conductor assumed an initial potential of about 30 per cent of that applied. This increased to 50 per cent when the impulse was applied to the middle and bottom conductor in parallel. It is to be noted that the potential of the free wire and of conductors carrying the surge have all come to the same value in a distance of 5.7 mi. Comparing the results of the chopped wave with those given in Figs. 3 and 4 for the fast and slow wave it is evident that the attenuation is greater with a single conductor than with simultaneous surges on multiple conductors, although this effect is much more pronounced with the chopped wave than with the others. This may be due to the transference of a larger percentage of the wave energy to the free conductors in the case of the chopped wave. Some indication of this energy transfer is found in the voltages measured on the free conductor, as shown in Fig. 6.

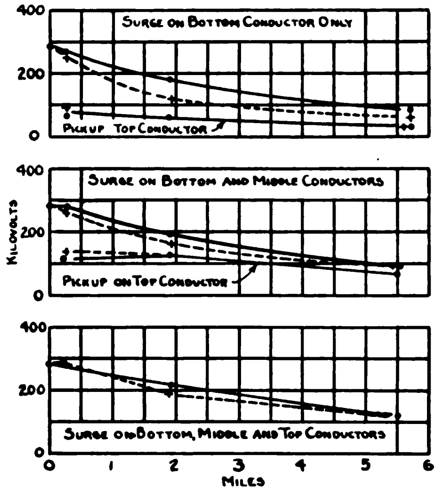

Fig. 6. Attenuation with Chopped Slow Waves on One, Two, and Three Conductors

Considerable work was done in the study of attenuation with ground wires, the results shown in Fig. 7 being representative of the results obtained. Two sets of curves are given, one with the top conductor grounded and one set with the top and middle conductors acting as ground wires. Plotted with these curves are the results for the same conditions with no grounded wires. The impulse was always applied to the bottom conductor at Tower C. Tests were made with both positive and negative impulses. In comparing these tests it should be remembered that the top and middle conductors are 8 ft. and 14 ft., respectively, from the bottom conductor, which means that the top conductor acting as a ground wire will influence the bottom conductor more than the middle wire will when it is grounded.

Referring to Fig. 7, the attenuation with the positive impulse seems to be only slightly affected by the presence of one or two ground wires, although the tendency seems to be definite at potentials above 200 kv. for a decreased attenuation with ground wires. Expressed in distance of travel, to suffer the same reduction in potential the positive impulse without ground wires traveled 5.8 mi. to reduce from 360 kv. to 190 kv. while with one ground wire the corresponding distance was 6.8 mi. and with two ground wires the distance was 7 mi.

With negative impulses of a potential of the order used in these tests the attenuation was considerably decreased by the presence of ground wires. To illustrate: From the curves without the ground wires it may be seen that the potential decreased from 380 kv. to 180 kv. in a distance of 7.4 mi. while with one ground wire the distance required for the same decrease was 14 mi. and with two ground wires, extrapolating the results slightly, this distance is of the order of 15 mi.

These results indicate that for positive impulses the ground wires have but little effect on the attenuation. In the case of negative impulses it appears that the presence of one ground wire so decreases the attenuation that the impulse may travel twice as far with the ground wire as without. Two ground wires increase this effect slightly. The idea that ground wires should damp out traveling waves quickly does not seem to hold; in fact the tests show that the reverse is true. This does not mean that ground wires are not useful in reducing the potential which would otherwise have been present when the line is under a discharging cloud, nor does it mean that the ground wire would not be helpful in case of a direct stroke of lightning to the ground wire or line wires. As shown in the section dealing with the study of ground wires, which follows, the reduction of potential during the release of the bound charge on the S-19 line is of the order of 20 per cent, while the calculated value was in the neighborhood of 23 per cent, considering the middle wire acting as the ground wire. When the top wire acts as the ground wire, the calculated reduction is of the order of 30 per cent and it is assumed that by test this reduction might also be of the order of 30 per cent. Assume by way of illustration that a potential of 460 kv. be taken as the induced potential without ground wire and 300 kv. as the potential on the bottom wire with the top wire acting as a ground wire. From Fig. 7 the respective attenuations for the bottom conductor bring the curves together after a travel of 7 mi., which means that as far as terminal apparatus is concerned the effect of the ground wire is lost after traveling over the distance of 7 mi. With the positive impulse, the case for the ground wire is better; for in traveling 7 mi. impulses which began as a traveling wave of 400 kv. without the ground wire and 260 kv. with it would be 170 kv. and 135 kv. respectively, which shows that the original 30 per cent difference had been reduced to 20 per cent by traveling 7 mi. on the S-19 line. In 11.5 mi. this difference has been reduced to about 10 per cent.

These tests indicate that the ground wire acts most efficiently when the storm is close to the point considered, as will always be the case with line insulators, or when storms are close to station apparatus. It is fortunate that this condition exists; for the most damaging impulses undoubtedly will be found nearest the point of inception.

Study of Ground Wires

A brief review of the theory of the ground wire will first be given in order that the significance of the tests to be described may be more fully appreciated.

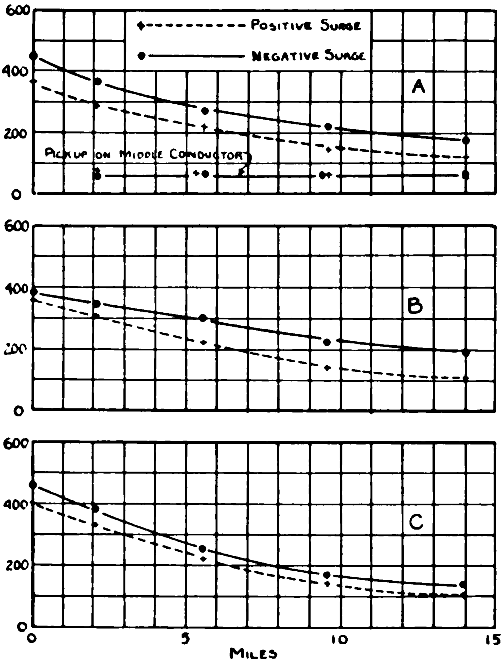

Fig. 7. Attenuation on Line Under Influence of Ground Wires

A—Top conductor grounded. *B*—Top and middle conductors grounded. *C*—No grounded wires.

When a cloud over a transmission line becomes charged, all of the conductors of the transmission line including the ground wires take up charges having a polarity opposite to that of the cloud. This action is easily understood when it is remembered that charges of unlike sign attract with the result that charges of a polarity opposite to that of the cloud are drawn up from the ground onto the ground wires while similar charges on the line conductors are not only drawn from the ground by leakage over insulators, but from other sections of line not under the cloud.

When the lightning discharge takes place, the charges on the ground wires are free to pass directly to the earth while the charges on the line conductors travel into other portions of the system as traveling waves. It is the function of the ground wires to reduce the potential appearing on the line conductors just after the lightning discharge takes place but before the charges begin to travel along the line wires. The mechanism of this reduction is frequently divided into two parts which will be referred to as the first and second actions of the ground wire.

It has already been pointed out in this article that when parallel conductors have charges of the same sign, the capacity to ground and the charges at a given potential are both less than they would have been without the charges on parallel conductors. This is exactly the case with the ground wire which initially has a charge of the same sign as that on the line conductors so that the line conductors have a smaller charge and a smaller capacity to ground because of the presence of a similar charge on the ground wire. It is assumed that the charge on the ground wire runs off to earth in zero time, so that the line conductors are found with an increased capacity, because of the elimination of the charge on the ground wire, but with the same charge that they had with the original capacity. As the product of the potential and the capacity is equal to the charge, which is constant, an increase in capacity results in a decrease in potential which constitutes the *first effect* of the ground wire.

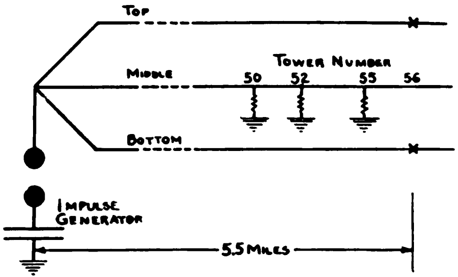

Fig. 8. Set-up for Study of Total Ground Wire Effect

The *second effect*, which is smaller in magnitude than the first, results from a further increase in capacity of the line conductors as the ground wires take up charges of the opposite sign. In this case the grounded conductor acts in a manner similar to that in which all of the conductors acted when they were in the original cloud field, except that the cloud field is replaced by the field of the line conductors to ground. The total effect of ground wires in reducing the potential on the line conductors during the release of a bound charge is the sum of the first and second effects. It is interesting to note that the sum of the first and second charges on one or more ground wires is just equal to the charges they would have had if no other conductors were present. For purposes of calculation, the first and second effects of the ground wire are conveniently considered together, and in the tests to be described the effects were studied together; but the second effect was also studied separately.

Study of the Total Effect

It is not possible to exactly reproduce the conditions existing in a cloud field with the apparatus at present available. However, a fair measure of the effect on the potential of the line conductors of changing the charge on the ground wire may be obtained by the use of traveling waves, although the ground-wire theory is predicated on static conditions. As pointed out previously, the potential of any one conductor is affected by charges on the parallel conductors, and this is true whether the charges are moving or stationary.

In making the tests to show the total effect, the three conductors were connected together at Croton Dam and an impulse applied to all three in parallel, as shown in Fig. 8. The middle conductor was grounded successively at Towers 50, 52, and 55 which had resistances of 76.4 ohms, 28.4 ohms, and 7.5 ohms respectively. Voltages were all measured at Tower 56.

Although in practice the different conductors will assume different potentials because of their different heights, this difference was neglected as being small, the same surge being applied to all three conductors. The surge applied had a front of about 10 microseconds and traveled a distance of 5.5 mi. to reach Tower 56, where the measurements were made. The results obtained are given in Table I and show the protective value of the ground wire which is the same for both positive and negative impulses.

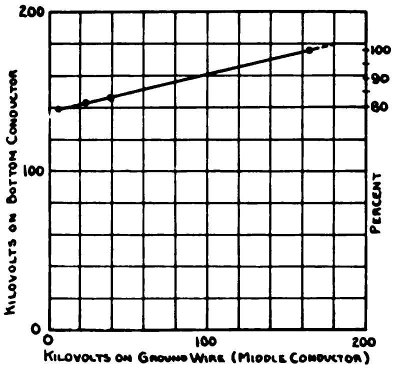

Fig. 9. Protective Factor Using Ground Wire

TABLE I

TOTAL GROUND WIRE EFFECT

Tower at Which Middle Conductor Was Grounded*	VOLTAGES MEASURED KV. AT TOWER 56			PROTECTIVE FACTOR	
	Top	Middle	Bottom	Top	Bottom
No grounds	178	168	177	100%	100%
50	...	40	146	...	83
50, 52	...	34	145	...	63.0
50, 52, 55	143	4.3	142	80.6	80.0

* The ground resistances were: Tower 50, 76.4 ohms; Tower 52, 28.4 ohms; Tower 55, 7.5 ohms.

The calculated protective factors for the total effect, assuming the middle conductor at earth potential, are 79 per cent and 77 per cent for the top and bottom conductors respectively.

The data obtained for the bottom conductor are plotted in Fig. 9 and show a protective factor of slightly less than 80 per cent where the curve crosses the zero ground wire voltage axis.

It is interesting to note that the greatest reduction of potential occurred at the first tower, although the tower resistance was 76.4 ohms, the ground-wire potential being reduced to 24 per cent and the line conductor to 83.5 per cent of the original values. This indicates that a large part of the benefit of the ground wire for reduction of induced discharges will be retained with tower footing resistance of the order of 75 ohms. Of course still better results will come from still lower resistances, particularly from the standpoint of direct strokes of lightning near the towers.

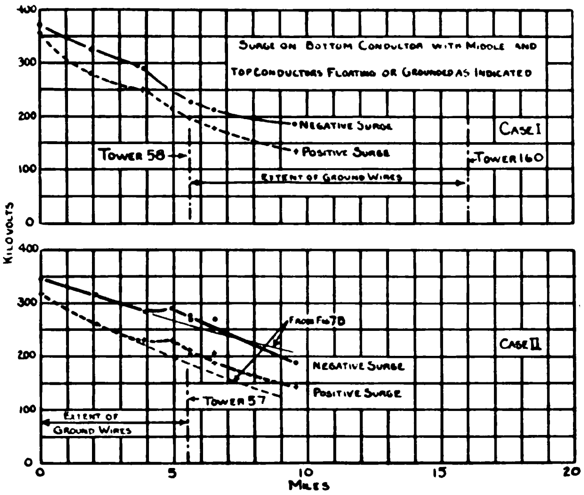

Fig. 10. Effect of Entering or Leaving a Section Equipped with Ground Wires on a Surge of Voltage

Numerous other tests have been made at different locations on the S-19 line, some with steel and some with copper ground wire, which also check the calculated values closely.

Study of the Second Effect

The second ground-wire effect involves a consideration of the change in potential of a conductor when the ground wire assumes a charge of opposite sign as a result of being placed in the field of the charged conductor.

In order to get test data on this effect a transition point was created on the S-19 line at a distance of 5.5 mi. from the impulse generator, which was far enough to give measurements unaffected by reflections from the impulse generator. At this point the top and middle conductors were cut. In one case grounds were put on the top and middle conductor from Towers 58 to 160, a distance of 11.5 mi., while the same conductors were left floating from Tower 57 to the impulse generator. Both positive and negative waves having fronts of seven microseconds were applied to the bottom conductor and voltage measurements made with spheres at suitable points along the line both in the grounded and ungrounded sections of the line.

This test was repeated under the reverse conditions, the top and middle conductors being grounded from Tower 57 to the impulse generator location. The impulses were applied as before to the lower conductor, and emerged from under the grounded conductors at Tower 57. These data are shown plotted in Fig. 10 and bring out some important conclusions. Considering Case I, in which the impulse enters the grounded section at Tower 57, a point of inflection occurs in the attenuation curves, which shows a reduction in potential due to the presence of the ground wires. The change in the curves occurs at a point about one mile back from the beginning of the ground wire section. The effect of the ground wires may be seen by extrapolating the curves without the ground wires, which indicates a reduction of about 8 per cent due to the ground wires. It should be possible to apply the attenuation curve *C* of Fig. 7 for the first three or four miles of this curve; but for some unknown reason curve *C* shows considerably increased attenuation for the same initial value of potential.

In Fig. 10, Case II, the attenuation curves are shown for an impulse passing from the ground wire section into a section without ground wires. In order to show the change in potential clearly, the attenuation curve *B* from Fig. 7 has been superimposed and indicates an increase of potential of 8 per cent for the negative impulse and slightly more for the positive impulse. As with Case I, the effect of the ground wire is felt a distance of about one mile back from the transition point. Measuring only crest potentials with a sphere-gap, the effect of the partial reflection would extend back from the point of change in impedance and for a distance slightly greater than half the length of the wave front. If the wave had been perpendicular, full crest potential would have been measured up to the reflection point, assuming, of course, no time lag for the measuring sphere-gaps.

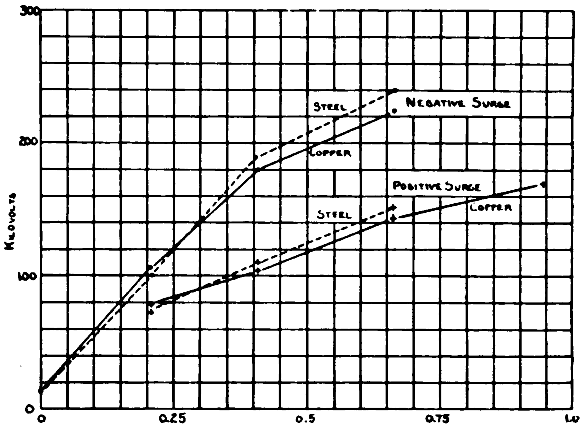

Fig. 11. Surge Voltage on a Steel or Copper Conductor Measured from a Grounded Point Back Toward the Impulse Generator

It should be noted in connection with these curves that the attenuation is much the same for positive waves, whether under the ground wire or not, while with the negative waves there seems to be a definite tendency for less attenuation under the ground wires. This situation is clearer in connection with Case II than it is with Case I. The results agree with those presented in connection with Fig. 7 under the general subject of attenuation.

Considering all of the values obtained, a value of eight per cent may be taken as the second ground-wire effect, which is to be compared with the six per cent calculated reduction when passing from a conductor having a surge impedance of 530 ohms to a surge impedance of 470 ohms which was calculated for the S-19 line with the top and middle conductors grounded.

Thus the sum of the first and second ground-wire effects gives a total reduction of 20 per cent for one ground wire. With two ground wires the first effect will be increased. The tests indicate that the second effect is not materially changed when two ground wires are used instead of one. These tests with traveling waves show that ground wires on a transmission line under a discharging cloud afford about that degree of protection indicated by the usual theoretical formula.

Copper vs. Steel Ground Wire

A limited number of tests were made in an effort to determine the relative merits of copper and steel conductors acting as ground wires. The tests made, which relate only to traveling-wave effects at comparatively low voltages, do not show any marked difference between copper and steel ground wires. One set of test results is given in Fig. 11, showing the voltage measured back along the grounded conductor from a grounded point. These waves show the copper to have slightly lower reflected potentials than the steel wire, but the difference is too small to be more than an indication. This curve is also interesting in that it shows that potentials as high as 200 kv. may exist a distance of 2000 ft. away from the grounded point, although much steeper gradients than this can no doubt be obtained with steeper waves. In the case under consideration the grounded point was at Tower 55, the steep wave impulse being applied at a point over five miles away.

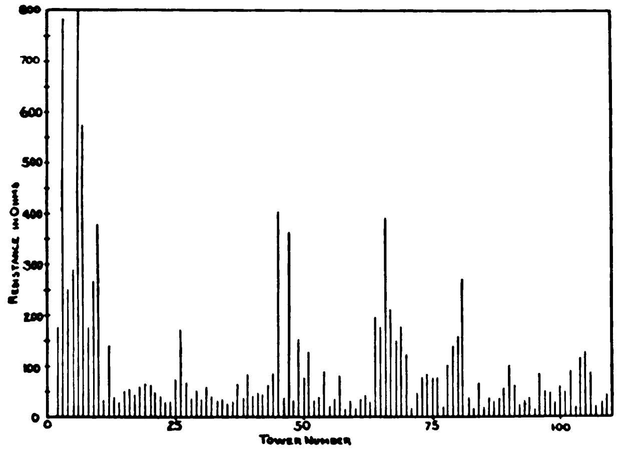

Fig. 12. Tower Footing Resistance on 10-mi. Section of S-19 Line

For protection from direct strokes of lightning the copper ground wire may have some advantage from the standpoint of current-carrying ability. Not enough is yet known about the direct stroke condition to make any definite statements regarding the relative merits of copper and steel.

Effect of Ground Resistance

In studying ground wires it is worth while to give some thought to the value of ground resistance under impulse conditions compared to grounds measured in the steady state. The effect of two ground resistances in parallel but varying distances apart will also be briefly considered.

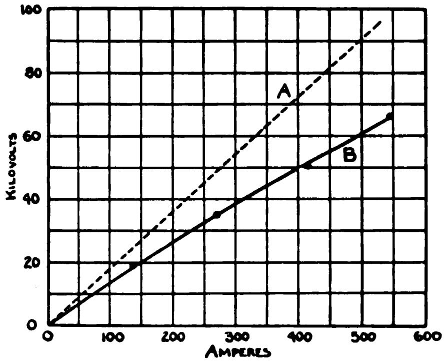

Fig. 13. Volt-ampere Curves of a Ground Resistance

Measurements of tower footing resistance were made with a megger constructed especially for this purpose. The resistances were found to vary from 12 to more than 1500 ohms. The resistances of tower footings over the section of line used in most of the tests described in this article are given in Fig. 12.

To measure a ground resistance under impulse conditions, a pipe was driven into the ground approximately 200 ft. from the impulse generator. An impulse current was sent from the generator through a water-tube resistance into the pipe ground. Sphere-gap measurements were made across the water tube and between the pipe ground and a stake in the ground far enough away not to be influenced by the current flowing in the vicinity of the pipe ground. In every case the transient resistance was less than that measured under steady-state conditions, which is in agreement with cathode-ray oscillograph tests made at Pittsfield.(12) The results of one such test are given in Fig. 13, which shows that the ground resistance with a transient current of 550 amp. is about 67 per cent of the steady-state resistance.

When a surge passes a point which is grounded through a resistance, the voltage is reduced according to the relation $E/E_o = 2\,R/(2\,R+Z)$, where E_o is the initial voltage and E the transmitted voltage. The per cent reduction due to varying values of resistance is shown in Fig. 14. When a wave passes two grounded points sufficiently far apart the reduction is correctly represented by applying this formula twice, once to the original wave and once to the transmitted wave which passes the first resistance. When this transmitted wave reaches the second resistance there will be a new transmitted wave beyond the second resistance and also a negative reflection traveling back toward the first resistance. Another reflection of reversed polarity will take place which will have the same polarity as the original wave. This wave will travel to the second resistance and the same operation will be repeated. If a rectangular wave is considered, each of the two resistances will operate independently if the distance between them is equal to more than half the wavelength. If the distance is less, the transmitted potential will be correspondingly higher until the condition is reached of a single resistance of half value when the distance between them is reduced to zero. This relation is shown in Fig. 15, which shows that if two resistances equal to one-eighth of the surge impedance are connected between line and ground farther apart than half the wavelength, only 4 per cent of the wave is transmitted; while if the same two resistances are connected at the same point the transmitted wave will be 11 per cent. This does not mean, however, that it is better to ground a ground wire at a few points far apart rather than many points close together, but it does indicate that two grounds of, for example, 50 ohms each are better if separated some distance apart than one ground of half the resistance in one location. This seems to indicate the desirability of keeping the ground resistance of towers uniformly as low as possible rather than having wide variations in tower footing resistance, even though some are low, but with a high average.

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(12) "Impulse Characteristics of Driven Grounds," by H. M. Towne, General Electric Review, Vol. 32, Nov., 1929, p. 605.

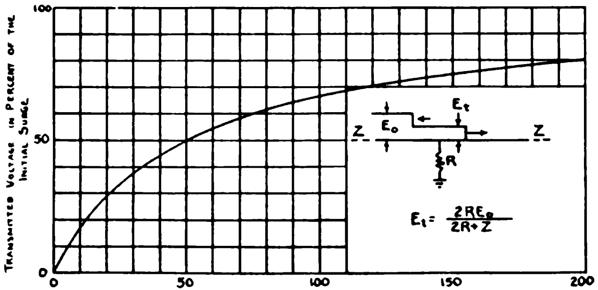


Fig. 14. Transmitted Surge Voltage Beyond a Resistance to Ground on a Continuous Line

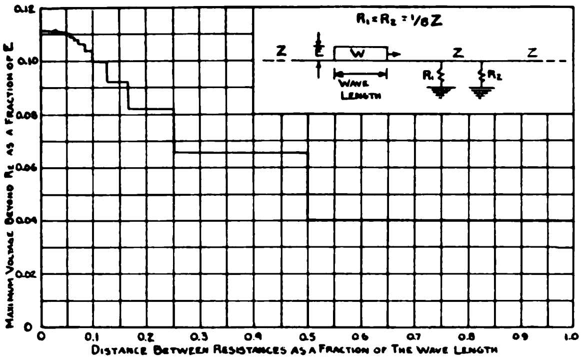


Fig. 15. Fraction of Rectangular Wave Transmitted Beyond Two Ground Resistances

In Table II it is shown how distance between resistances affects the transmitted wave when using surges having a front of approximately 10 microseconds. The test values which were measured at spacings of 500 and 5000 ft. lie in the range that would be expected from the theory.

Measurement of Surge Impedance

Some difficulty has been experienced in measuring the surge impedance of the transmission line conductors. The method finally adopted was to connect a variable resistance between line and ground at a point sufficiently remote from the generator to be sure that traveling wave conditions were established and to plot a curve between amperes through the resistance and the potential to ground, as in Fig. 16. The current values are determined from the potential measured across the grounding resistor, while the voltage measurements are taken between the line and a separate ground at a point such that the IR drop in the resistance of the ground is included. If the measurement is not made at the end of a line, the voltage at zero current is to be divided by one-half of the current at zero volts, which will give the surge impedance. If the measurement is made at the end of a line remote from the generator, the voltage at zero current divided by the current at zero voltage will give the surge impedance. The advantage of this method lies in the

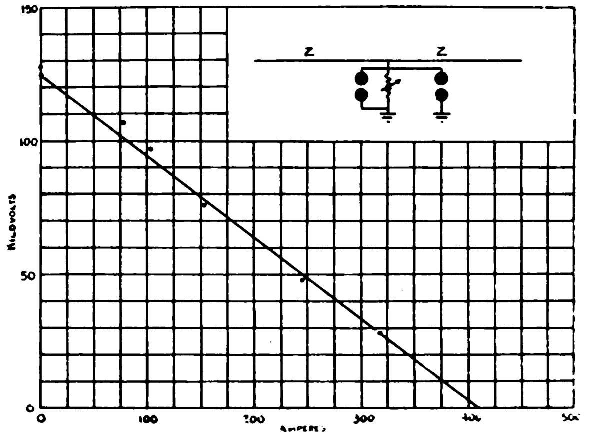


Fig. 16. Determination of Surge Impedance by Measurement of Voltage and Current to Ground with a Variable Resistance and Sphere Gaps

TABLE II

EFFECT OF DISTANCE BETWEEN RESISTANCES TO GROUND ON THE PROPAGATION OF A SURGE

Voltage Measured at	SPACING BETWEEN RESISTANCES			
	Zero*	500 ft.	5000 ft.	Distant*
R_1	56 kv.	56 kv.	51 kv.	56 kv.
R_2	30	21	10	7.7
R_3	10.3	8	3	1.1

*Calculated assuming R/Z =8 per cent.

possibility of determining the curve quite accurately by taking measurements with several resistances without being forced to measure the current at zero potential.

Conclusions

A million-volt impulse generator of sufficient capacity for field use with limited power facilities available has been shown to be satisfactory in use, and still higher potentials can be obtained when necessary.

The tests have shown the following:

(1). Surges attenuate less rapidly when other nearby parallel conductors are carrying similar surges.

(2). In general, positive surges attenuate more rapidly than do negative surges, although in some tests but little difference was found.

(3). Short waves, such as a wave chopped on the front by an insulator flashover, attenuate more rapidly than do longer waves of the same crest value.

(4). An additional constant has been introduced into the formula for attenuation which seems to give better agreement with the test results.

(5). The presence of the ground wire reduces the attenuation considerably for the negative wave and to a lesser degree for the positive impulse. This decrease in attenuation is important if found to be universally true, for it tends to cancel the reduction of induced potential as a result of a discharging cloud after the resulting traveling wave travels a distance of several miles. This of course does not affect the reduction in potential due to the ground wire at the point of inception.

(6). The ground-wire theory of reduction of induced potentials was checked, using traveling waves. The results agree with the protective ratio for the ground wire given by the usual calculation. For the conductor arrangement used, the calculated reduction was 23 per cent, while the test showed 20 per cent reduction for the total ground-wire effect.

(7). The second ground-wire effect was also checked with traveling waves and it was found that, when entering or leaving a section with one or two ground wires, the surge voltage was decreased or increased 8 per cent respectively. These approximate the calculated value based on the change in surge impedance. These results indicate that very little is to be gained by putting up additional ground wires near a station to reduce an incoming impulse. From the standpoint of additional protection from lightning discharges which originate close to the station, their use may be justified.

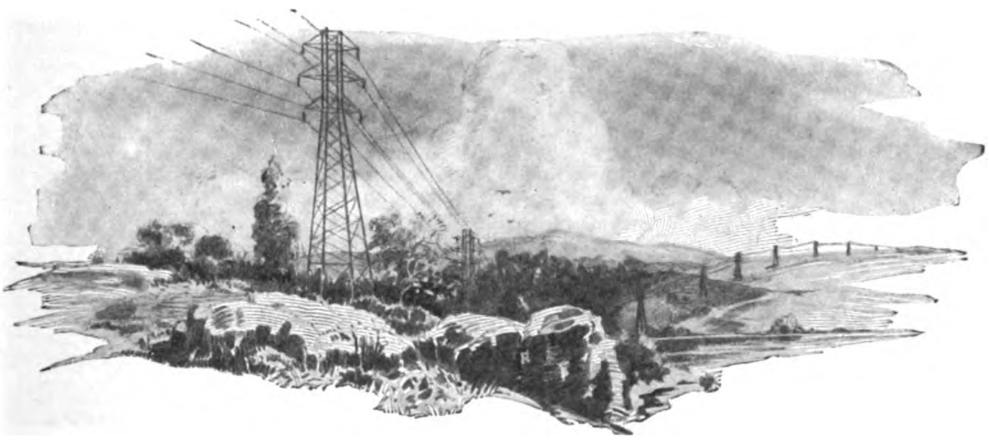
(8). The test indicates that there is little difference between steel and copper conductors from the standpoint of their ability to transmit impulses.

(9). The theory of voltage reduction due to two resistances at varying distances apart, connected between conductor and ground when subjected to traveling waves, was checked by test. This work shows that if but two grounds of equal value are to be used the greatest reduction in wave transmitted beyond the resistances occurs when the resistances are at least half a wavelength apart. Thus two resistances of 40 ohms a half mile apart will more effectively ground the line than one resistance of 20 ohms. This seems to indicate that uniform low resistance is preferable to widely varying resistances.

(10). Transient ground resistance is less than the resistance measured under steady-state conditions.

(11). The surge impedance of a transmission line may be satisfactorily determined from a series of voltage and current readings with varying values of resistance between line and ground.

The writers wish to express their appreciation to the officials of both the Consumers Power Company and the General Electric Company who have made this joint investigation possible. Much credit is due to Messrs Brune, Eaton, Wade, and others who were responsible for conducting the tests in the field and to Messrs. Boehne, Brinton, and Brownlee who also assisted in the preparation of the article.



LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

Alternators

160,000-Kw. Generator Goes Into Operation at the New York Edison Company's Plant. D. S. Snell.
Power, Dec. 31, 1929; v. 70, pp. 1030-1034.
(Illustrated description.)

Arc Welding

Automatic Arc Welding. W. L. Warner.
Amer. Weld. Soc. Jour., Dec., 1929; v. 8, pp. 9-20.

Electric Welding of Field Joints of Oil and Gas Pipe Lines. Harold C. Price.
Am. Weld. Soc. Jour., Oct., 1929; v. 8, pp. 28-41.
(Arc welding methods and equipment.)

Material Transference in the Welding Arc. A. Hilpert.
Am. Weld. Soc. Jour., Dec., 1929; v. 8, pp. 21-23.

Condensers, Synchronous

Condenser Pays Dividends. B. E. Morrow.
Elec. Wld., Jan. 11, 1930; v. 95, pp. 94-96.
(Economies effected by the use of a synchronous condenser on the system of the Consumers Power Co., Jackson, Mich.)

Dynamics

Dynamical Analysis of Machines. R. Eksergian.
Franklin Inst. Jour., Jan., 1930; v. 209, pp. 21-36.
(Serial.)

Electric Current Rectifiers, Solid Contact

New Application for the Rectox Rectifier. Harry La Viers, Jr., and Herbert S. Littlewood.
Coal Min., Dec., 1929; v. 6, pp. 589-592.
(For insuring correct polarity in automatically-controlled synchronous converters.)

Electric Distribution

Why Networks Are Used. D. K. Blake.
Elec. Wld., Jan. 18, 1930; v. 95, pp. 146-148.
(Discusses the low-voltage a-c. network having a 115/199-volt, four-wire transformer secondary connection and utilizing the low-voltage network protector.)

Electric Furnaces

Economic Use of Electric Furnaces. Wirt S. Scott.
Iron Age, Dec. 26, 1929; v. 124, pp. 1725-1728.
("Analysis of production costs, electricity vs. natural gas in heat treatment of high grade shovels.")

Induction Furnaces.
Engr., Dec. 20, 1929; v. 148, pp. 652-654.
(Illustrated account of the construction and operation of various types. Serial.)

Electric Lamps, Gas Tube

Operation of Neon Tubes. J. K. McNeely and R. P. Ballou.
Elec. Wld., Jan. 11, 1930; v. 95, pp. 99-102.
("Laboratory tests on cold-cathode tubes under various conditions of energy supply furnish data significant to operation and indicate possibilities of new uses.")

Electric Lighting—Aviation

Marking the Modern Air Route. A. K. Toulmin Smith and H. N. Green.
Aircraft Engng., Jan., 1930; v. 2, pp. 11-15.
(Deals with lighting air routes and airports.)

Electric Measurements

High-Tension Metering. H. M. Sanders.
Elec. Wld., Dec. 14, 1929; v. 94, pp. 1168-1169.
("Features of equipment used on 220,000-volt lines for measurement of transfer power.")

Electric Motors, Induction

Polyphase Induction Motors; A Labor Saving Method of Calculating Performance From Previously Determined Constants. W. J. Branson.
A.I.E.E. Jour., Jan., 1930; v. 49, pp. 29-33.
(Abridgment.)

Electric Motors, Induction

Quiet Induction Motors. L. E. Hildebrand.
A.I.E.E. Jour., Jan., 1930; v. 49, pp. 7-11.
(Discusses the various causes of noisy operation and remedies.)

Electric Shock

Effects of Electric Shock. W. B. Kouwenhoven and Orthello R. Langworthy.
A.I.E.E. Jour., Jan., 1930; v. 49, pp. 25-29.
(Results of experiments on rats to determine the effect on the central nervous system. Abridgment.

Electrical Machinery, Synchronous

Three-Phase Short-Circuit Synchronous Machines—V. R. E. Doherty and C. A. Nickle.
A.I.E.E. Jour., Jan., 1930; v. 49, pp. 38-41.
(Abridgment.)

Electricity—Applications—Bridges

Motors and Control for Movable Bridges. H. W. Pittenger.
Engng. News-Rec., Dec. 19, 1929; v. 103, pp. 970-973.
("Basic factors to be considered in selecting electrical equipment for bascule, swing, and vertical lift bridges.")

Electricity—Applications—Clocks

Synchronous Motor Clocks. G. E. Moore.
Engr., Dec. 27, 1929; v. 148, pp. 682-684.
(Illustrated account of several such devices, including the Warren clock.)

Hydroelectric Development

Hydraulic Power Accumulation. A. Page.
Elec. Rev., Dec. 27, 1929; v. 105, pp. 1131-1134.
(Engineering and economic features of pumped storage schemes.)

Insulation—Testing

Ionization Currents and the Breakdown of Insulation. J. J. Torok and F. D. Fielder.
A.I.E.E. Jour., Jan., 1930; v. 49, pp. 46-50.
(Abridgment.)

Lightning Arresters

Theory of a New Valve Type Lightning Arrester. J. Slepian and others.
A.I.E.E. Jour., Jan., 1930; v. 49, pp. 34-37.
(The possibilities of utilizing discharges confined to the fine pores of a porous material. Abridgment.)

Measuring Instruments

Applications of the Electric Balance to the Continuous Solution of Mathematical Formulae. Perry A. Borden.
Instruments, Dec., 1929; v. 2, pp. 425-432.
(List of nine bibliographic references, p. 432.)

Mercury Turbines

Emmet Mercury Vapor Process. W. L. R. Emmet.
Engrs. & Engng., Dec., 1929; v. 46, pp. 282-284.
(From a paper presented before the World Engineering Congress, Tokyo, Japan.)

Protective Apparatus

Metropolitan-Vickers "Translay"; An Improved Method of Balanced Protective Gear for Feeders. T. W. Ross.
Met.-Vick. Gaz., Nov., 1929; v. 11, pp. 414-419.
(Serial.)

Minimizing Fault Damage Within Generators. Lloyd F. Hunt.
Elec. Wld., Dec. 28, 1929; v. 94, pp. 1263-1265.
("Two types of differential protection are compared with a scheme which does not automatically drop machine but gives audible signal of trouble.")

Protecting 2300-Volt Motors. B. W. Jones and G. F. Lincks.
Ele., Wld., Jan. 18, 1939; v. 95, pp. 149-150.

Radio Communication, Aircraft

Air Transport Communication. R. L. Jones and F. M. Ryan.
A.I.E.E. Jour., Jan., 1930; v. 49, pp. 50-54.
(Abridgment.)

Civil Airways and Their Radio Facilities. H. J. Walls.
Inst. Radio Engrs. Proc., Dec., 1929; v. 17, pp. 2141-2157.

Plane and Ground Communication by Radio. Frank L. Curtis.
Aviation, Dec. 28, 1929; v. 27, pp. 1262-1264.
("A brief study of the Pan-American radio system and its development.")

Radio for the Air Transport Operator. Lester D. Seymour.
Inst. Radio Engrs. Proc., Dec., 1929; v. 17, pp. 2137-2140.

Radio Engineering—Measurements and Testing

Method and Apparatus Used in Testing Piezo Oscillators for Broadcasting Stations. E. L. Hall.
Bur. Stds. Jour. Res., Jan., 1930; v. 4, pp. 115-130. (RP No. 135).

Resistors

Non-Metallic Resistance Electric Heating Elements.
Engng., Dec. 20, 1929; v. 128, pp. 814-815.
(Applications of the "Globar" resistor, particularly for electric furnaces.)

Ship Propulsion, Electric

More Power With Less Fuel.
Met.-Vick. Gaz., Dec., 1929; v. 11, pp. 438-447.
(Illustrated description of installation on S.S. *City of Hongkong* includes results of trials.)

Standards, Electric

Gas-Filled Lamps as Photometric Standards. Ray P. Teele.
Illum. Engng. Soc. Trans., Jan., 1930; v. 25, pp. 78-96.

Steam Plants

Steam Pressure and Temperature. Frank S. Clark.
Power, Dec. 10, 1929; v. 70, pp. 932-935.
(Abstract of a paper before the World Power Conference in Tokyo. Considers the effect of pressure and temperature on thermal efficiency.)

Television

Television Reception Tests. F. H. Haynes.
Wireless Wld., Dec. 18, 1929; v. 25, pp. 669-673.
("An endeavour to receive the television broadcast, with details of the apparatus used.")

Transformers—Load Ratio Control

Tap Changing Under Load for Voltage and Phase-Angle Control. Homer B. West.
A.I.E.E. Jour., Jan., 1930; v. 49, pp. 42-46.
(Discusses equipment and connections. Abridgment.)

Transformers—Temperatures and Cooling

Operating Transformers by Temperature. W. M. Dann.
A.I.E.E. Jour., Jan., 1930; v. 49, pp. 3-6.
(Discusses a proposal, sponsored by an A.I.E.E. subcommittee, that transformers be operated by temperature rather than by nameplate ratings.)

Vision

New Science of Seeing. M. Luckiesh and F. K. Moss.
Illum. Engng. Soc. Trans., Jan., 1930; v. 25, pp. 15-49.
(A study of the theory of vision. Special attention to causes and prevention of glare.)

Welding

Contribution to the Study of Influence of Welding Conditions and Subsequent Heat Treatment on the Structure of the Weld. Karl Kuettner and V. N. Krivobok.
Am. Weld. Soc. Jour., Dec., 1929; v. 8, pp. 40-62.
(Very detailed paper analyzing various methods of welding. Numerous bibliographic references.)

NEW BOOKS

(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.)

Business Reports; Investigation and Presentation. Alta G. Saunders and Chester R. Anderson. 411 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $3.50

Dielectric Phenomena in High-Voltage Engineering. Ed. 3. F. W. Peek, Jr. 410 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $5.00.

("It is the object of the author to give in this book the properties of gaseous, liquid, and solid insulations, and methods of utilizing these properties to the best advantage in the problems of high-voltage engineering. . . . . Methods that have proved useful in designing apparatus, transmission lines, insulators, bushings, etc., are discussed and illustrated by practical application. In addition, such subjects as the manner of making extensive engineering investigations and of reducing data, the measurement of high voltages, the effects of impulse and high-frequency voltages, methods of drawing dielectric fields, outline of modern theory, various dielectric phenomena, etc., are considered." Due to the increase in laboratory and field data on high-voltage phenomena since the second edition of this book, it has "seemed desirable to make a thorough revision at this time and to add the most recent material." The new material includes results of recent studies of corona, of impulse breakdown in gases and insulation, of breakdown in solid and liquid insulation, and of sparkover voltages in gaps and insulators at very high voltage. A separate chapter on lightning is included.)

Einführung in die Komplexe Behandlung von Wechselstromaufgaben. Ludwig Casper. 121 pp., 1929, Berlin, Julius Springer. R. M. 6.60 (paper.)

(This small German book deals with the application of complex vector algebra to alternating-current problems. Starting with the simplest examples, the author covers the ground quite thoroughly. The different chapters deal with circuits containing resistance, reactance, and capacitance in multiple and in series; the equations for the equivalent diagram of an alternating-current network with distributed constants; equations for geometric loci, in vector form, of alternating-current apparatus such as induction motors, repulsion motors, and series commutator motors. The equivalent circuit and its symbolic solution of a string-type and condenser-type insulators is also presented. The 121 clearly-written pages, with the 42 diagrams, and the numerous examples make this booklet a useful one for the engineer who wants to become acquainted with this subject.)

Electricity; What It Is and How It Acts. Vol. 1. Andrew W. Kramer. 274 pp., 1929, Chgo., Tech. Pub. Co. $2.00.

("This book. . . . . is not an elementary study of electrical engineering. It is not concerned with the solution of practical electrical problems, nor is any attempt made to deal with the constructional features of electrical equipment. It is a work, rather, which deals with the fundamental principles which underlie the laws upon which electrical engineering is based." The author has attempted to explain, in a logical manner, the part played by the electron in electrical phenomena,—the structure, arrangement and behavior of electrons. and their contribution to the various manifestations studied in electrical engineering. The treatment is as simple as the nature of the subject will permit; in fact, the same material originally appeared in serial form in *Power Plant Engineering*. This first volume considers only those phenomena which are not concerned directly with electromagnetic radiation. A second volume will be devoted to radiation phenomena, radio-activity, the electron theory of magnetism, and related topics.)

Electromagnetic Field. Max Mason and Warren Weaver. 390 pp., 1929, Chgo., Univ. of Chicago Press. $6.00.

Experimental Radio. Ed. 3. R. R. Ramsey. 255 pp., 1929, Bloomington, Ind., R. R. Ramsey. $2.75.

(As the author states in the preface to his first edition, this is not a textbook, nor does it contain any great amount of theoretical matter. It is, in reality, an elementary laboratory manual for students of radio engineering. Laboratory test procedures for the various radio phenomena are outlined, being followed immediately by illustrative experiments. "Some experiments, methods of test and practical directions for the construction of apparatus have been inserted for those who have not had college physics or who do not have access to regular physical apparatus.")

Industrial Accounting; Control of Industry Through Costs. Thomas H. Sanders. 371 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $4.00.

Industrial Economics. Dexter S. Kimball. 312 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $3.00.

Industrial Furnace Technique. A. Hermansen. 293 pp., 1929, Lond., Ernest Benn, Ltd. 25 sh.

Internal-Combustion Engines; Theory and Design. Ed. 3. Robert L. Streeter and Lester C. Lichty. 445 pp., 1929, McGraw-Hill Book Co., Inc. $4.00.

Introduction to Mechanics. J. W. Campbell. 384 pp., 1929, N. Y., Houghton Mifflin Co. $3.50.

(A textbook for college students. It "presupposes no previous knowledge of mechanics, and the plan is to build a theory, complete in so far as it goes, and not dependent upon mechanical theory obtained from other sources." The author has quite definite ideas regarding the teaching of mechanics, and these he has outlined briefly in his preface in an attempt to explain his reasons for presenting the subject as he does. He makes use of simple calculus from the outset, and emphasizes the importance of a thorough grounding in the abstract theory. In his own words: "The book aims to give a clear conception of fundamental ideas and not at giving a treatise on special topics.")

Introduction to Physical Optics. John K. Robertson. 422 pp., 1929, N. Y., D. Van Nostrand Co. $4.00.

Ions, Electrons and Ionizing Radiations. Ed. 5. James A. Crowther. 253 pp., 1929, N. Y., Longmans, Green & Co. $5.00.

Kinematical Design of Couplings in Instrument Mechanisms. A. F. C. Pollard, 64 pp., 1929, Lond., Adam Hilger, Ltd. 4s.6d.

(The author, who is Professor of Instrument Design at the Imperial College of Science and Technology, explains, in this little booklet, the application of a kinematic theorem to the design of couplings for measuring instruments. He considers not only the various indicating instruments, but control instruments such as thermostats, voltage regulators, governors, etc. Instrument variance, accuracy, and sensitivity are discussed, and instrument couplings with various degrees of freedom are studied.)

Loki; The Life of Charles Proteus Steinmetz. Jonathan N. Leonard. 291 pp., 1929. Garden City, N. Y., Doubleday, Doran & Co. $2.75.

Machine Design. P. H. Hyland and J. B. Kommers. 448 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $4.00.

Mechanical Equipment of Buildings. Vol. 1: Heating and Ventilation. Ed. 2. Louis A. Harding and Arthur C. Willard. 963 pp., 1929, N. Y., John Wiley & Sons. $10.00.

Mechanics of the Gyroscope. Richard F. Deimel. 192 pp., 1929, N. Y., Macmillan Co. $4.00.

Modern Aviation Engines. Victor W. Pagé. 2 vols., 1929, N. Y., Norman W. Henley Pub. Co. $9.00.

Numerical Tables of Hyperbolic and Other Functions. J. W. Campbell. 76 pp., 1929, N. Y., Houghton Mifflin Co. $1.25.

("The main purpose in compiling these tables has been to provide tabular values of hyperbolic functions in a form readily accessible for practical use." In addition to tables of the fundamental hyperbolic functions, such as sinh x, there have been included tables of the quotient functions, such as $(\sinh x)/x$, for use in solving catenary problems. Convenient tables of circular functions of numbers are also presented. "Notes on the Tables" and a "Handbook of Formulae" are included in a brief appendix.)

Oil Engine Power Plant Handbook. Ed. 5. 288 pp., 1929, N. Y., National Trade Journals, Inc. $5.00.

Psychology and Industrial Efficiency. Harold E. Burtt. 395 pp., 1929, N. Y., D. Appleton & Co. $3.00.

Quantum Mechanics. Edward U. Condon and Philip M. Morse. 250 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $3.00.

Radio Manual for Radio Engineers, Inspectors, Students, Operators and Radio Fans. Ed. 2. George E. Sterling. 797 pp., 1929, N. Y., D. Van Nostrand Co. $6.00.

("A guide and text book for those who expect to enter the radio profession as engineers, inspectors, servicemen, or as operators of commercial, broadcast, or amateur stations. Much of the material will also be of interest to the radio fan." It considers installation, upkeep, operation, and control of amateur and professional radio equipment. Some of the more important topics treated are: transmitting and receiving apparatus and technique, broadcasting methods, television and radio motion pictures, radio direction-finding, radio communication for ships and aircraft, interference problems, radio laws, radio traffic handling, etc.

Report Writing. Carl G. Gaum and Harold F. Graves. 319 pp., 1929, N. Y., Prentice-Hall. $5.00.

Scientific Management in American Industry. The Taylor Society. 479 pp., 1929, N. Y., Harper & Brothers. $6.00.

Theory and Design of Electric Machines. F. Creedy. 349 pp., 1929, N. Y., Isaac Pitman & Sons. $9.00.

(The subtitle of this text tells us that it is "a treatise dealing with the fundamental principles of the design and operation of all types of electrical machines" and "containing a novel method of arriving at the correct dimensions for any particular design." We are also informed that it "represents an effort to reduce the study of the dynamo electric machine to a scientific form and to introduce order where, owing to the enormously rapid rate of development, there is little sign of it at present." It is the author's endeavor to present a general survey of the theoretical possibilities of the future. This he does by starting from the most abstract point of view, where the general machine is looked upon as a special case of Maxwell's equations of the electromagnetic field. Then he introduces limitations one after the other, with explanations, thereby dividing the general machine into special classes which he then proceeds to describe in detail. The thirty chapters are grouped into six parts as follows: "General Theory of the Dynamo-Electric Machine," "The Classification of the Dynamo-Electric Machine," "Cascade Apparatus," "Variable Pole Machines," "Polyphase Commutator Apparatus and Its Applications," and "Principles of Design.")

Transmission Networks and Wave Filters. T. E. Shea. 470 pp., 1929, N. Y., D. Van Nostrand Co. $6.50.

(A treatise on the calculation and design of telephone networks and wave filters, based upon the experiences and research activities of the Bell Telephone Laboratories. After an introductory chapter on the place of transmission networks in electrical communication systems, the author devotes four chapters to the principles, theory and performance of such networks; four chapters to wave filters and their applications; and two chapters to the nature and solution of transient waves. A bibliography of books, articles and patents involving collateral reading is included. By its very nature, the subject matter is necessarily technical, and the treatment is therefore such as would appeal to the specialist in telephone engineering and similar work.)

Wirtschaftliche Erzeugung der Elektrischen Spitzenkraft in Grossstadten. E. Krohne. 66 pp., 1929, Berlin, Julius Springer. R. M. 6.00 (paper).

(The author of this German booklet on the generation of peak power in large cities has gathered his material from experiences and investigations in the generation and distribution of electric energy in the city of Berlin. His findings should prove valuable for operating and designing engineers. Definite relations in the economical generation of peak power are presented and discussed. Two extreme cases for the generation of this power are considered, namely, generation at the place of application, and generation at a point remote from that place. For these two conditions economic rules are developed. Initial, operating, and fuel costs are compared for the generation of peak power by steam plant, by Diesel plant, and by schemes involving energy storage. In case the peak-load generating station is remote from the load, a material increase in cost per kilowatt-hour is found.)

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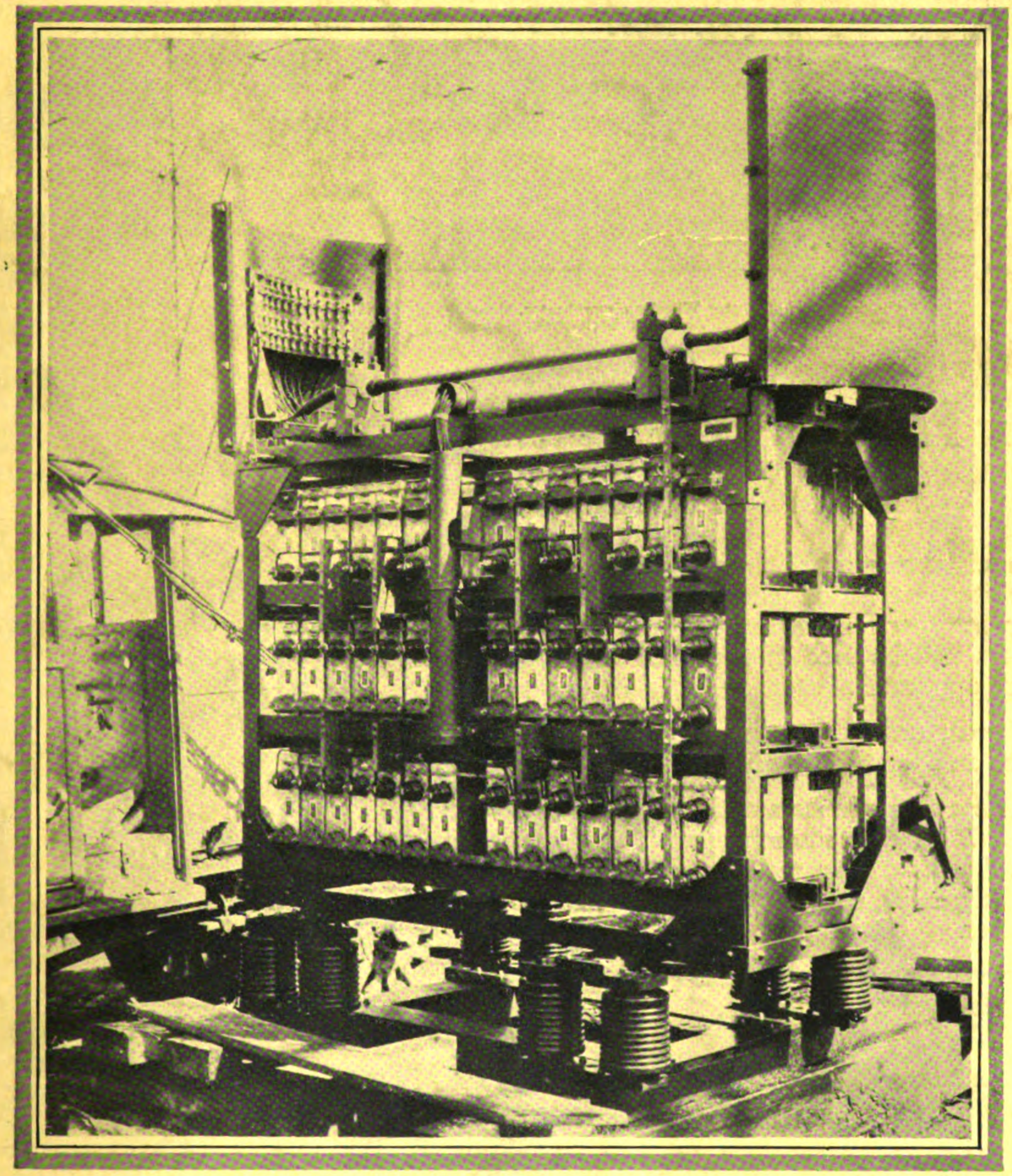
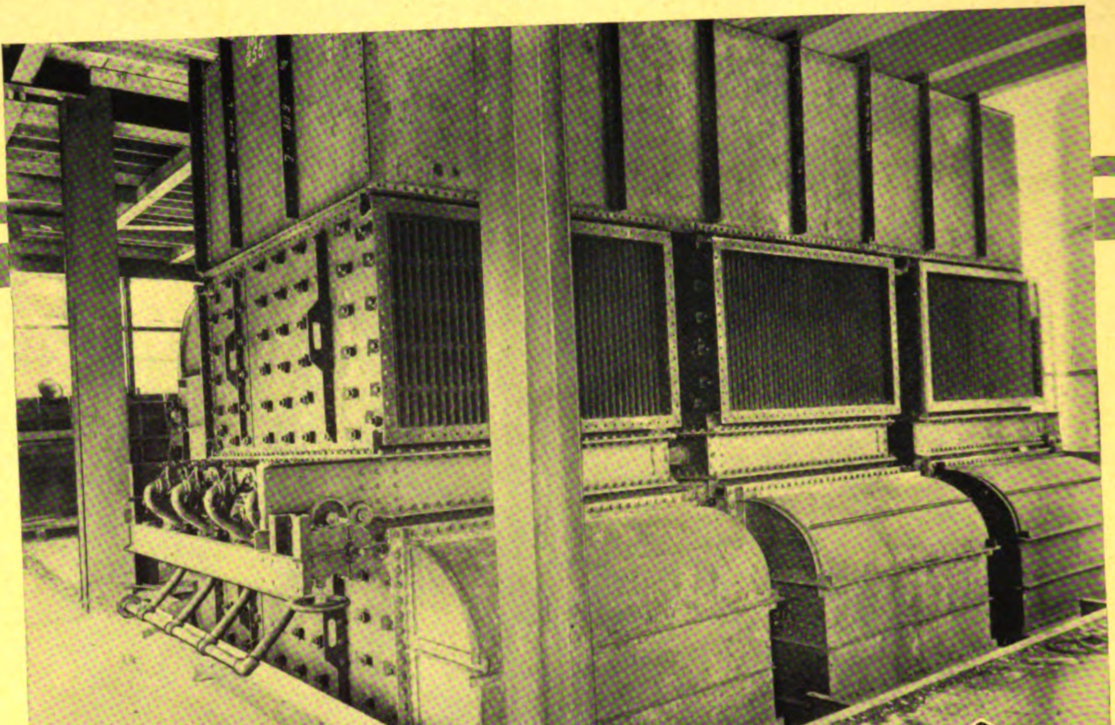
VOL. 33, NO. 5 MAY, 1930



INSIDE THE SERIES CAPACITOR TANK

Photograph taken of one of the three 415-kv-a. 3170-volt single-phase capacitors of the pioneer installation at Ballston (N. Y.) when the capacitor was being equipped with terminal boards by means of which the individual units can be tested or spare units placed in service without removing the assembly from the tank. The effect of series capacitors on the voltage regulation of transmission circuits was analyzed in our August, 1928, issue. Their effect on the steady-state stability of power systems is explained in this issue (p. 279)

n This Issue: ***The Theorem of Constant Linkages*** ***Series Capacitors and Stability***
Street Lighting Circuits ***Modern Physics*** ***Heat Transfer in Compressors***
Crystal Orientation ***The Three-phase Arc Furnace*** ***Ultra-violet Emanations***



Upper section of Foster Wheeler air preheater, showing three parallel groups. Air flows horizontally through the sections.

Air Preheaters Duplicated in Central Station Service

In eighteen months the original Foster Wheeler air preheater installation (shown above) was followed by a repeat order for two more preheaters. All the air heaters will be used in the same central station and all are duplicates.

Repeat orders are the strongest recommendation which an operator can give.

These air preheaters each contain 29,000 sq. ft. of surface. Twelve interchangeable sections comprise each heater. The sections are arranged in three parallel groups, each group consisting of four sections in series.

Each air preheater supplies an 1862-hp. boiler with air preheated to 394 deg. F.

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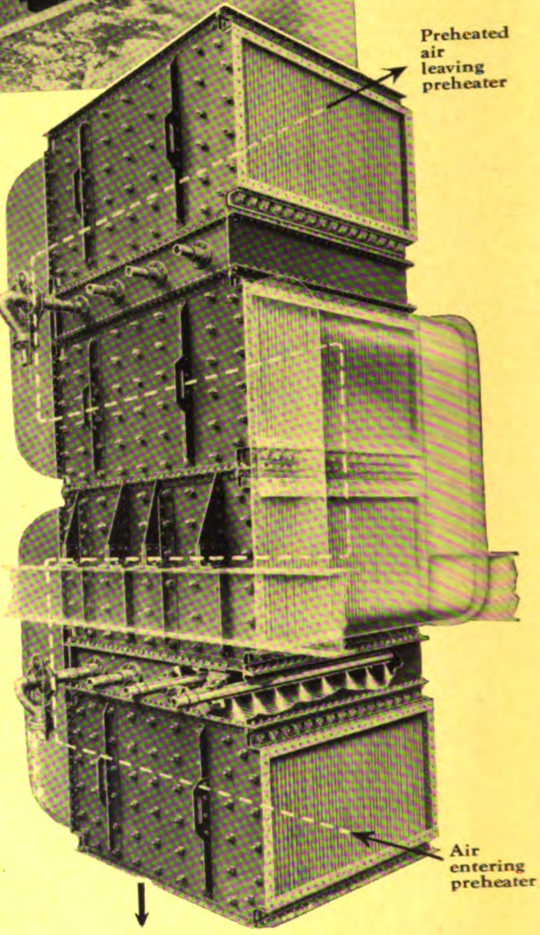
Preheated air leaving preheater
Air entering preheater
Cooled gases leaving preheater

Arrangement of four sections of the Foster air preheater, placed one above the other. The dotted line with arrows, indicates the path of the air flowing through the sections. Gases pass vertically downward through the heater.

FOSTER WHEELER

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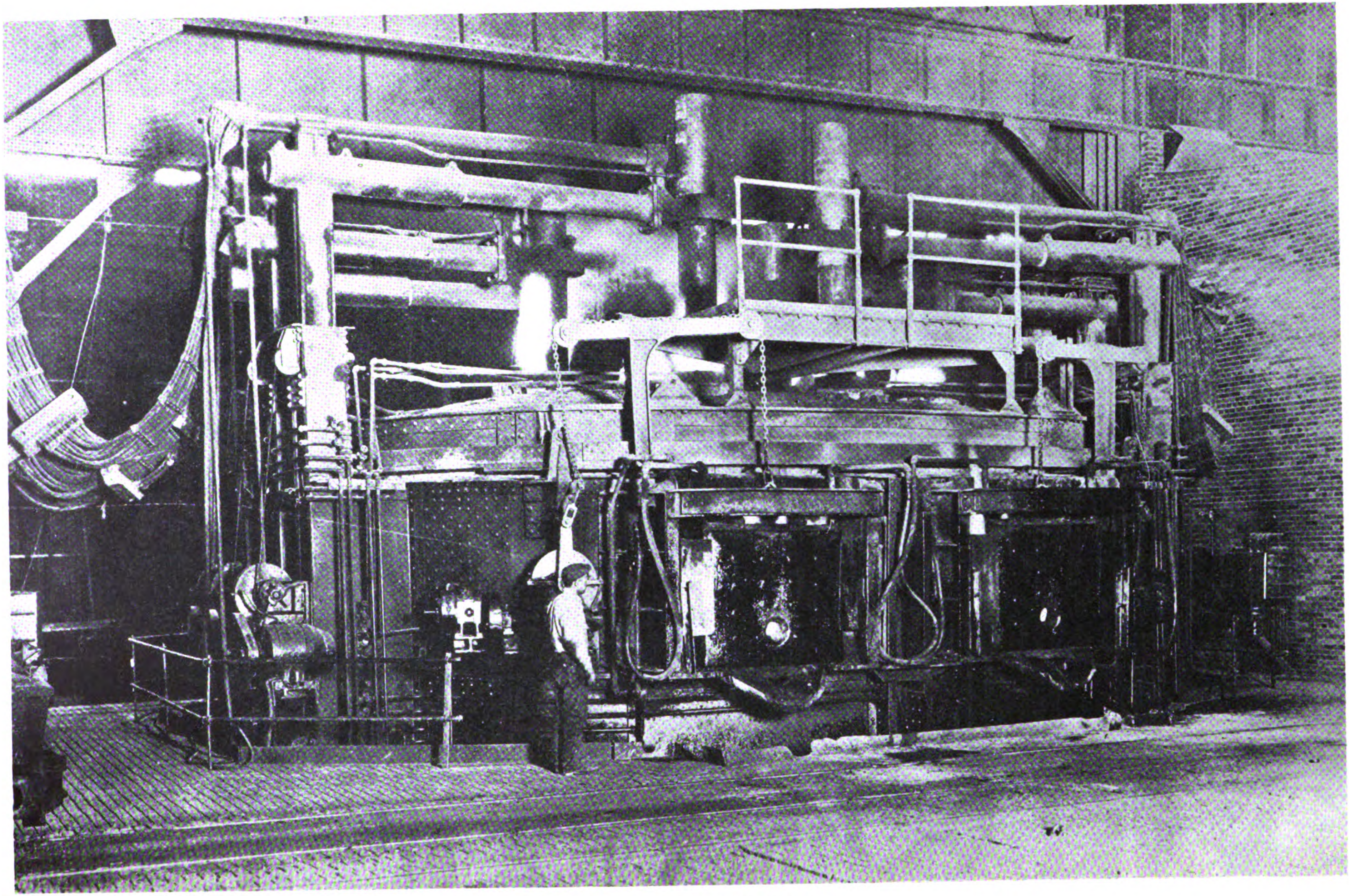

MODERN PRACTICE OF VULCAN'S ART

An 80-ton three-phase arc furnace used in the manufacture of alloy steel. The furnace embodies two sets of electrodes, each supplied by a 10,000-kv-a. transformer. Descriptions of such furnace installations and their operation are given in N. R. Stansel's serial on p. 316 of this issue, and in earlier issues

GENERAL ELECTRIC REVIEW

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RATIONALIZATION AND THE ENGINEER

Among the readers of this and other technical journals are some engineers and scientists who limit their thoughts too closely to their own profession. They may even have become rather one-sided through over-earnestness to make progress in the realization of their conceptions regarding important engineering improvements and innovations. They bury their heads in the sands of engineering facts (and fancies) and are apt to be oblivious to the importance of the big non-engineering realities in the world about them. Such characteristics are rather trying to better-balanced folks.

With the rapidly accelerating pace of industrial developments, the importance of rationalization can hardly be over-emphasized. In 1927 the World Economic Conference at Geneva defined "rationalization" as:

> "The methods of technique and organization designed to secure the minimum waste of either effort or material. It includes the scientific organization of labor, standardization both of material and products, simplification of processes, and improvements in the system of transport and marketing."

Engineers would be inclined to assume from this definition that the term "rationalization" may be applied broadly to the intelligent direction of our efforts to promote human welfare efficiently. We believe we can show that an understanding of rationalization will make our earnest engineer less impatient of and more reconciled to the delays and seeming indifference which he encounters.

To what lengths should engineers go in their endeavors to advance their plans for improving standardized products and for the development of new products to supply human needs? It is probably correct to state that a few hundred years ago scientists announced really important advances in scientific knowledge at the rate of not more than a very few every year or so. Even that constituted over-production since the demand was practically nil. These few progressive ideas were in those days rarely received with eagerness. Imprisonment or persecution were often their reward. Now-a-days, novel and important scientific improvements are encouraged, and are being introduced at the rate of thousands every year. It is probable that American manufacturers are annually assimilating as large a number of the improvements submitted to them as is consistent with the maintenance of their large volume of production and the enlarging of it to meet the increasing demands of consumers. Improvement requires change. If everything should be too frequently changed, the volume of production could not be maintained, even at increased cost. On the other hand, too little or too infrequent change jeopardizes a reputation for providing the best.

Looked at from this standpoint, one feature of rationalization relates to the process of regulating the rate of introducing changes. The more able the management and the staff, the greater may be the frequency or the extent to which the product may be improved without sacrificing volume of production or increasing cost. But even with the most favorable conditions, there will be limits to the extent to which, or rate at which, even admittedly important improvements can be made in the product. It is quite within reason that it will often be impossible promptly to take advantage of more than a small percentage of excellent available improvements, all of which it would be very desirable to embody in the product if this could be accomplished without delaying production.

Some idea of the magnitude of the market for electrical engineering products and of its rate of increase may be gathered from the fact that while in 1922 the investment in this country in electric utility undertakings was about five billion dollars, it had in 1928 (that is, in the brief space of six years) increased to ten billion dollars. This rapid rate of increase is being maintained notwithstanding rapid changes in the kind, and numerous improvements in the quality, of the machinery. Thus higher steam pressures and temperatures are continually being employed in boilers and turbines. The sizes and speeds and voltages of electric generators and motors are changing and, for most applications, are continually moving upwards. Completely different machines and materials, such as large steel-tank mercury-arc rectifiers, arc-welded generators and motors, oil-filled 132,000-volt underground power-transmission cables, tap-changing-under-load transformers, and many other important innovations have within the last few years been introduced into electric generating and transmission systems in America. Presumably the criterion (even if not wholly recognized by its appliers) has been to introduce as many improvements as possible while maintaining the volume of production at the amount called for by the rapidly growing needs of the country.

But as already suggested, there are limits to the rate at which it is economically permissible to incorporate changes into manufactured products. The embodiment of a new principle in an actual working machine is now in most cases a far more elaborate undertaking than it would have been during earlier pioneer periods. Some of us can recall the days when the largest transformers built in this country were rated at 7.5 kw. and were wound for 2300 volts on the high-pressure side. The largest transformers of the present day have a rating ten thousand times greater, namely 75,000 kv-a., and they are wound for pressures as high as 230,000 volts, that is, for a voltage one hundred times that of the early days. In the design and manufacture of the early transformers but a few people were engaged, the manufacturing machinery was inexpensive, and but a few kinds of materials were employed. For the large transformer of today, many more varieties of materials are required, each the result of careful investigations and each supplied to exacting specifications. The collaboration of many specialists in dozens of different fields of knowledge is also essential. The problems of these specialists relate to the phenomena of magnetism and hysteresis and aging in alloyed sheet steel, to its composition and method of manufacture, to its pre-treatment, annealing, forming and assembly, to the properties and manufacture and insulation of the conductors and to ways of constructing them into primary and secondary windings. There are also problems concerning the many complicated characteristics of transformer oil, the design of the conservator, the water-cooling coils, the radiators, and the other features of the method of cooling, and there are many complicated considerations relating to the thermal resistance of oil films, water films and air films, and the influence of different speeds of circulation of these media on the rate of heat transfer. The problems of arc welding the mechanical members, the assurance of complete oil tightness at dozens of vulnerable places, the provision of means of resisting enormous mechanically destructive forces during short circuits, the provision of protection against lightning and surges, the proportioning of the windings for the desired reactance, the transposition of conductors in the complicated ways essential to minimizing load losses, the tap-changing-under-load features employed in many designs—all these and many other problems of transformer design and construction call for a whole army of specialists. No one of these specialists can possibly have more than relatively superficial knowledge of the subjects for which the others are responsible. Among these specialists may be mentioned oil chemists, insulation chemists, physicists in heat flow, in corona and other dielectric phenomena, in wave and surge occurrences, and in magnetic properties; as well as metallurgists, mechanical engineers, and electrical engineers.

Under these involved circumstances, the introduction of even minor changes in design or construction requires vastly more caution and circumspection than was adequate in the early days of the industry. Any change in one feature, regarded desirable by the specialists having it in charge, must be carefully considered with reference to its consequences in the remainder of the design which is in the field of the many other specialists. Nevertheless, since transformers of any such very large size as that mentioned are custom made, it is usually in them that changes and improvements are most freely introduced and not in the small mass-produced sizes. Thus it is not so paradoxical as at first it appears, that changes and improvements are apt to be made first in large transformers and, after being thoroughly tried out in these large transformers, are later extended to small transformers.

Turning now to this other extreme, namely, the mass production of small transformers, it must be realized that these must be made by continuous processes in enormous numbers. Consequently, while each one is of comparatively small value, any fault of design or construction or performance in service will occur in each transformer of this enormous quantity. The situation requires the most exhaustive studies and tests to be made prior to adopting the slightest desired improvement. The completed transformers must successfully withstand the most severe factory tests and subsequently must function perfectly throughout their period of service. While with mass production the disclosure of any weakness at as late a stage as the occasion of factory tests of the product after mass production has commenced is an incident of major seriousness, it is still vastly more serious to have some type of defect which does not develop until after a considerable time in service.

Similar considerations apply in varying degrees to rotating machines of all kinds, to switches and circuit breakers, and to many other products. They apply (with the reservation already explained about the very large transformer, namely, that it is custom made) to very large sizes of these machines, of which only one is made at a time, and to small machines of which tens of thousands are made alike by mass-production methods. It is evident that much time and study and expenditure and severe artificial accelerated life tests must precede even the slightest change in any of these products.

Instead, then, of being impatient, we can only marvel when we realize that the admitted frequent and great changes and improvements in electrical machinery are being accomplished coincidently with the present rapid expansion of the industry.

As a particularly impressive example of rapid and efficient development, let us turn from the subject of electrical machinery for electric utility systems and briefly examine the newest important application of electricity as an industrial tool. We refer to electric arc welding. This process has now been employed as an alternative to and improvement upon riveting in the erection of many large steel-frame buildings. It has also already been employed in the construction of several bridges of minor importance and will certainly soon be widely applied to large and important bridges. Hundreds of miles of pipe line for transporting oil and natural gas and water have been joined by arc welding and it is widely used in the construction of dynamo-electric machinery, large extra-high pressure tanks required in chemical and other processes, for joining rails, and for hundreds of applications in the fitting up of ships. There are already a few medium-sized ships whose hull plates have been joined by arc welding instead of by riveting. It is inevitable that the general application of arc welding to joining the hull plates of ships will not long be deferred. It is hard to realize that any serious industrial use of arc welding in this country was almost negligible as recently as fifteen years ago.

Notwithstanding this rapid advance, the earnest engineer frets at the inadequate interest shown in his proposals to improve and speed up arc-welding processes. From his standpoint he is quite justified, but since arc welding is only one of many important developments which must be fitted into the rationalization program of the engineering industry, it can receive only its proportionate share of attention and development expense.

Of other notable instances of novel and particularly important electrical machinery and methods, which are now in the process of being rapidly introduced and must receive their share of attention, let us mention the steel-tank mercury-arc power rectifier, the use of hydrogen for cooling electrical machinery, the use of electric motors for driving ships' propellers, Diesel electric locomotives, automatic and supervisory control of machinery in stations and substations, oil-filled underground cables, domestic refrigerators, and many other household labor-saving and health-conserving devices.

One hundred years ago the receptivity to most of these propositions would have been so indifferent that the engineers who initially advocated them would in many instances not have lived to see even the beginning of their realization. Now, the engineer often need be patient only for a few years.

To any one of a considerable number of this country's largest manufacturing corporations there are being constantly submitted vast numbers of proposals for the improvement of their product and for new products. These propositions must be considered with regard to the limitations imposed by the rationalization of the available manufacturing facilities, and their normal extension. For these reasons only a small percentage of the proposals can be employed, and then only after a great amount of work has been done on each proposal to demonstrate its practicability. But even after eliminating the 90 per cent of less urgent plans for improvement, there are probably assimilated into practice each year hundreds of times as many improvements and novel products as was the case only a quarter of a century ago.

After all, engineers and scientists are working on these kinds of things because they like to. If it were only the matter of making a good living, they might better engage in selling securities or insurance or in writing melodramas for the talkies. Such activities would, however, be too prosaic or too devoid of serious purpose to afford any satisfaction to folks with scientific minds. We believe that on the whole the engineer and scientist is especially fortunate in the choice of his immensely interesting life work. He should understand the reasons for, and be reconciled to, delays and to considerable indifference toward the proposals which to him are so important. The indifference should not be taken as a reflection upon the importance of his work; it is inevitable for the reasons we have stated.

We have now endeavored to examine whether the engineer is justified in being impatient as regards the lack of enthusiasm with which his proposals are often received and as regards the delays in their reduction to practice, and we have explained that industry at the present stage of its rationalization simply cannot assimilate changes, however attractive, at more than a certain rate determined or limited by economic laws. We can be reconciled to this limitation since it is reasonable and inevitable.

But there is another side to the matter.

Discontent and impatience should be encouraged rather than denounced since they are necessary in order to offset stagnation and dangerous complacency which are much more usual than discontent and impatience. We have already mentioned as typical examples of rapid changes that in the course of a very few years the steam pressures employed in service have been increased from 200 lb. per sq. in. to several times as much, and that still higher pressures are being considered. Steam temperatures are also increasing. The pressures and temperatures employed in tanks and pipes in chemical processes are rapidly being raised. Constantly improving materials, and improved processes of joining them, and skill in design, are making these things possible.

In many other directions great changes have also been accomplished in very short intervals. One has only to mention the use of electricity in locomotives with Diesel-electric drive, in the rapid increase of sizes and in many cases of speeds of prime movers and motors, in the drive of ships' auxiliaries, and in turbine-driven generating sets supplying propeller-driving motors. Engineers and scientists know full well that any considerable departures from usual engineering practice, such as those just mentioned, have been opposed by many of their colleagues in the engineering profession. Indeed, it should be admitted that it is the complacency of some engineers rather than complacency on the part of executives, which is often a serious obstacle to change and improvement. Moreover, those engineers are apt to fail to realize that the just-accomplished step, whatever it may be, is the beginning and not the end.

"Last year we developed a machine which increased our operating speed 50 per cent."

"Good. This year I suppose you will go still higher?"

"No. We find the present speed is exactly the most suitable, and higher speeds would have serious disadvantages."

But someone, in spite of every possible discouragement, doubles the speed and overcomes the disadvantages. Why this lack of vision by even a minority of the very folks on whom the world depends for progress? Let us examine other instances: For example, it is announced that a certain machine has been re-designed to embody one amongst several new features (that had been rejected a few years before).

"But we understood from you, a while ago, that the economy would not be improved but even impaired by introducing this feature."

"Well, we were wrong."

"Are you going to adopt any of the other features that you rejected a while back?"

"Oh, no. This new design is exactly the most economical (and always henceforth will be, world without end, amen)."

But while the words are being uttered, someone, somewhere, is further increasing the economy by a machine that embodies those features.

A new machine is developed. Someone suggests an improvement. In answer the claim may be made that the improvement cannot be incorporated because the customer insists on such or such a characteristic. Someone makes the improvement and obtains not only the "such or such characteristic" but a still better result in the respect for which the customer is stated to have been solicitous. Unperturbed we may be told that the improvement is nevertheless undesirable: this feature will be too low; that feature will be too high; almost anything superficially plausible is given by the complacent individual as the reason for disparaging the suggested improvement. But although this attitude has been observed many times, invariably after years the denounced improvements are adopted. We no longer permit our confidence to be disturbed by the superficial assertions of these chronic objectors, but we admit to inability to be reconciled to the wasteful and completely inexcusable delays and discouragements which are the consequences of their opposition to improvements.

Perhaps, however, some cautious Providence has decided that it is desirable for 90 per cent of engineers to put the brakes on the remaining 10 per cent in order to give the necessary opportunity for the assimilating processes and thus save industry from being buried under the ever-impending avalanche of better ways to do things. But the statistical showing of an ability to rationalize the utility business at a doubled rate every six years affords assurance that the rate of assimilation of improvements is capable of being still further immensely increased and that in the near future there will be less need for delaying their adoption.

If the present rate of growth of the electrical business continues, then twelve years hence we shall have on our hands forty billion dollars worth of electric generating and transmitting material in place of the present ten billion dollars worth. Would it not be a pity that the additional thirty billion dollars worth should not embody a maximum of improvements? The greater part of the machinery which was made twelve years ago is now so inferior and so near obsolescence that soon it could well be scrapped. So just because the material which we are at present using still represents an outlay of ten billion dollars, we should not have too much reverence for it. Much of this machinery looks good to us now, but twelve years hence we shall regard it very differently. Indeed, experience tells us with considerable certainty that obsolescence will take place faster in the next six years than was the case in the preceding twelve years, just as the preceding twelve years is comparable in this respect to the still earlier twenty-four years. We must recognize the extent to which human activities are speeding up.

Reviewing the past, at one time the benefits of water power were available only at the site, and elsewhere reciprocating engines were the only source of power greater than animal power. Until a comparatively late date, the transmission of electricity was confined to metallic circuits. During a certain early period, direct current seemed to fulfill all the requirements for electrical service. Not so many years ago, most power plants were each an entity in itself, and each, operating in isolation from the others, served only its local community.

Today, the energy of the waterfall is spread state wide as alternating current and pooled with power from the successively larger fuel-fed rotating prime movers. Radio has released quick communication from the confines of wires. In consideration of the progress already made it would be indeed rash to claim that even these represent the ultimate developments in those branches of engineering. They are certain to be far different within the next few decades.

H. M. HOBART

The Educational Value of the Theorem of Constant Linkages

The Theorem Defined—Typical Applications in Analysis of Problems—Relays of Various Types—Application to Mutually-linked Circuits—Analysis Applied to a Transformer—Other Applications—Scope of Utilization

By F. C. LINDVALL

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THE Theorem of Constant Flux Linkages is an extremely valuable concept in electrical theory, yet since its introduction some years ago(1) it has remained in comparative obscurity. A few engineers who have been concerned with transient phenomena in electrical machinery have come to realize the convenience and usefulness of the theorem in analyzing their problems. Still it has not received the general recognition that it warrants. In particular, the conception of constant linkages merits a place in the formal study of electromagnetic theory.

New interpretations, new forms, new versions of old principles which clarify individual thinking in adapting theory to specific applications are invariably welcomed in the study of engineering problems, since no single exposition or formulation of a fundamental law can have a general appeal. Thus the theorem of constant linkages, though it in no way adds generality to the basic law of induction, affords a new viewpoint, a new analytical tool, and should prove particularly valuable to anyone engaged in a study of induction. In turn, the simplicity and power of the theorem are definitely attractive, as experience in technical instruction of graduate character given to young engineers at the General Electric Company has shown. Accordingly this article was written in an effort to make the theorem generally better known, particularly to the faculty and students in the technical schools, and, perhaps, thereby to stimulate academic interest.

In substance the theorem of constant linkages is a statement that in any closed electrical circuit of negligible resistance the number of magnetic-flux interlinkages (the product of turns and flux) tends to remain constant. Another statement is that "a closed electric circuit, without resistance, must persist magnetically in the same condition as at the instant of closing; *i.e.*, must contain, so long as it is closed, the same number of magnetic interlinkages." (1)

As to the validity of the theorem a simple proof will suffice.(2) In the usual way, a voltage equation may be written for a closed circuit which contains only resistance and self inductance. According to Kirchhoff, the sum of the voltages around the circuit is

$$0 = Ri + \frac{d}{dt}(Li)$$

R, L, and i having the usual meanings, resistance, self-inductance, and current. Now postulating no resistance in the circuit, the equation at once yields the result

$$0 = \frac{d}{dt}(Li)$$

which, by the definition of inductance, is a direct statement that the magnetic interlinkages remain constant.(3)

In this proof the assumption of zero resistance in the circuit is made, and, to a certain extent, the scope of the constant-linkage theorem is thus limited. Still, a large number of situations arise, as in the study of electrical machinery under short-circuit conditions, in which the resistance of the circuit is small compared with the effect of the self-inductance and may without appreciable error be ignored. The effect of this small resistance appears principally in the decrement of the current subsequent to the moment of occurrence of the transient, and it does not seriously impair the accuracy of the results obtained by applying the theorem to the initial transient conditions. Furthermore, in problems involving resistance that cannot reasonably be neglected and to which the theorem is thus not legitimately applicable, it is nevertheless of value in analysis and as a qualitative check on any solution obtained by other methods.

Thus the constant-linkage theorem is seen to be a logical deduction from the basic law of electromagnetic induction and Kirchhoff's law of voltages, and a pertinent question may be raised as to the existence of any advantage which this new concept may have over the original versions. That advantage should manifest itself, in the following examples, as a means of simplifying the study of transient problems, adding clarity in understanding, and effecting a direct solution. Or, the salient point to be noted is that this particular formulation of the law of induction constitutes a valuable tool for achieving direct analyses of certain transient electromagnetic phenomena, and for studying certain types of relay operation.

As an example consider a physically simple arrangement which often leads into difficulties of analysis.

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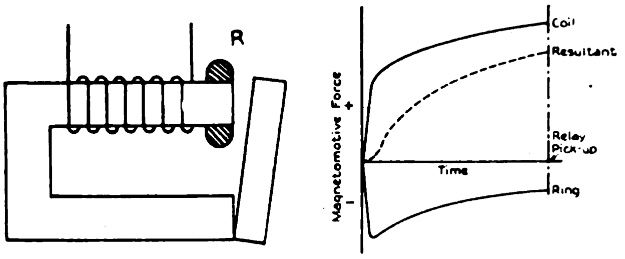
(1) "Reactance of Synchronous Machines and Its Applications," by R. E. Doherty and O. E. Shirley, *A.I.E.E. Trans.*, 1918, p. 1209.

(2) This deduction may readily be generalized, if desired, to include any number of multiple circuits and any arrangement involving mutual flux. For such a derivation see "A Simplified Method of Analyzing Short-circuit Problems," by R. E. Doherty, *A.I.E.E. Trans.*, 1923, p. 841.

(3) The relation that Li is a constant quantity is interesting when considered in terms of the electromechanical analogy. The inductance represents mass in the mechanical system, and the current represents velocity. Accordingly, the theorem of constant linkages is precisely analogous to the principle of conservation of momentum in mechanics. For further details concerning the electromechanical analogy see "Oscillographic Solution of Electromechanical Systems," by C. A. Nickle, *A.I.E.E. Trans.*, 1925.

Imagine a heavy copper ring into which has been inserted one end of a long bar magnet, and that some time has elapsed so that any induced current no longer exists. The situation is thus a closed circuit of very low resistance, and of self inductance L, linked with a definite amount of flux. If the magnet now be removed, what current will be induced in the ring, and what work must be done in removing the magnet? Since no change can occur in the number of linkages, a current must be established in the ring as the magnet is removed in order to hold the linkages constant at the original value. The magnitude of this current can readily be computed from the amount of original flux. Of course, the current I now flowing represents, in terms of the self inductance, a stored energy of $1/2\ LI^2$, which is simply the work done in removing the magnet, This example, solved at once by the theorem, would doubtless present some difficulty to one attempting blindly to apply the usual relation that induced voltage is proportional to rate of change of flux.



(a). Elementary Diagram (b). Relay Characteristics

Fig. 1. A Relay Utilizing a Heavy Copper Ring for Producing Time Delay

Were the resistance of the ring zero, the induced current would continue to flow indefinitely. With resistance, however, this energy is gradually dissipated as I^2R loss so that ultimately the current flow ceases.

Now, with no current in the ring, and, accordingly, no flux linkages, let the magnet again be inserted. In order that the value of zero linkages be maintained a current must again be established in the ring to counteract the force of the magnet, giving thus a highly distorted field.

This bit of speculation suggests the attractive limiting case of the ring at absolute zero of temperature where, as experimental and theoretical evidence indicates, the ideal condition of zero resistance is attained.(4) Such a closed circuit having no resistance whatever satisfies entirely the conditions imposed in the statement of the theorem of constant linkages. Suppose, further, that as the ring was brought to this state of zero resistance it linked with no flux. Then, no matter what may be the form or strength of any magnetic field into which the ring may subsequently be placed, no flux whatsoever can link with it. Current of any value necessary to oppose the threading of flux through the ring will flow and will vary with any changes in the external field. Such a situation is indeed a striking example of what has been aptly termed "the eternal perversity of inanimate matter."

Practically, though, some resistance is always present in any closed circuit, and, as a result, opposition to changes in flux can be only of a transient nature. That is, while a ring of heavy cross-section opposes, through the establishment of current, any changes in flux, the induced current ultimately diminishes to zero and the flux then exists quite independently of the ring.

This simple arrangement has been utilized to great advantage in time-delay relays of the type indicated in Fig. 1. The relay has the usual mechanical details with the armature normally held away from the core by a spring or by gravity. The coil is energized with direct current and if the heavy copper ring R were not about the iron core the armature would immediately be attracted. The original state of no flux through the ring must be maintained, however, so that only as the resistance of the ring brings about a decay in its induced current can flux become established across the air gap and finally attract the armature. Lowering the resistance of the ring interposes a longer time delay, and similarly, increasing its resistance quickens the relay action. Thus the device may be made for quite a range in time lag, and has the additional important advantage of thoroughly consistent operation. Moreover, such a relay gives a similarly delayed opening after the coil circuit is broken, a feature that may or may not be a valuable adjunct to the retarded closing.

Another type of relay designed for delayed opening, utilizing this same principle of constant linkages, is sketched in Fig. 2. The coil is energized and the armature is drawn to the core, giving a large iron path through which considerable flux passes. Through some external arrangement the coil is short-circuited when the relay action is to commence. The flux linkages within the short-circuited winding must remain initially constant, or, in other words, the current must continue to flow subsequent to the short circuit. Resistance of the coil, however, causes the current to diminish and after a definite lapse of time the armature is pulled away from the core by a spring, thus making back-contacts C.

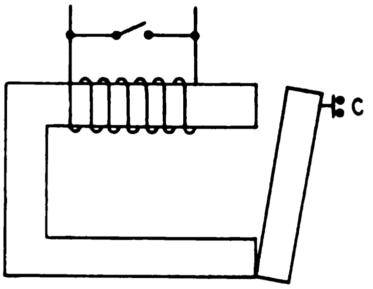


Fig. 2. A Relay in which Time Delay is Produced Through Short-circuiting of Operating Coil

This relay has numerous applications in control apparatus, as, for example, in shortcircuiting in sequence sections of starting resistance. The coil of one relay is energized from the voltage drop across a section of resistance. When that portion is short-circuited the relay holds in for its period of time delay, and then releases, closing the contacts which cut out a second section of resistance.

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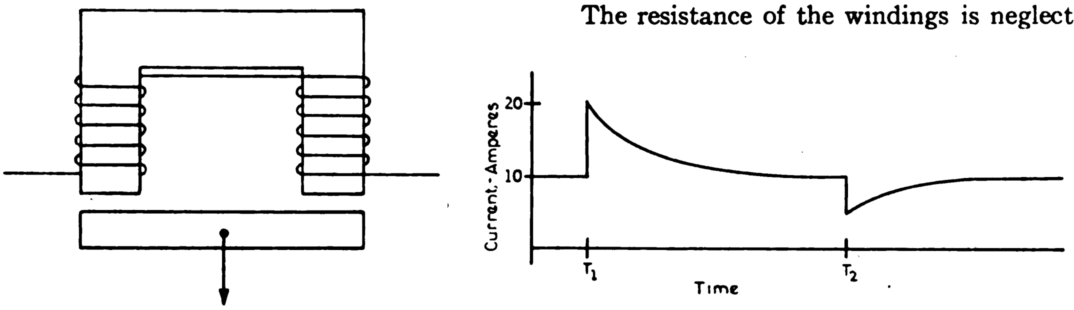
(4) E. Henning, *Ann. d. Phys.* 40, 635; 1913. *SS. Phys.* 5, 264; 1921. Kammerlingh-Onnes, *Comm. Leyden Ur.*, 1914.

Another example of more theoretical than practical interest is the arrangement in Fig. 3. The distance between the armature and the poles is 0.2 cm. The coil is connected to a low-voltage d-c. source, resulting in a steady current of 10 amp. Suppose now that the armature be jerked away suddenly from the poles so that the air gap is doubled. What will be the effect on the current in the coil? The current in the windings must change in order to maintain the original value of flux. The reluctance of the magnetic path has been approximately doubled, neglecting the reluctance of the iron in comparison with that of the air gap, so that practically twice the magnetomotive force, or twice the current, is needed to maintain constant flux linkages. That is, the current, originally 10 amp., jumps suddenly at the movement of the armature to about 20 amp.; then owing to the resistance of the circuit the current falls exponentially to the steady-state value of 10 amp. The final value of flux will be about half of that originally existing.



(*a*). Essential elements

(*b*). Graph of operation in which T_1 represents conditions with armature pulled away; T_2 with armature dropped back

Fig. 3. A Device for the Control of Current Flow by Variation of Air-gaps

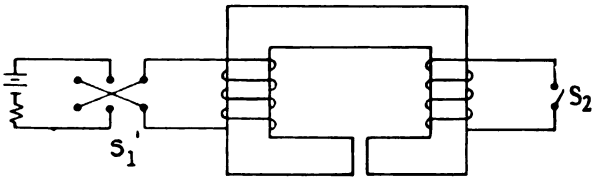


Fig. 4. Transformer Circuit Supplied by Means of Battery and Reversing Switch

If the armature be allowed to drop back to its original position, the reluctance of the circuit is suddenly cut in half. The current must therefore fall to 5 amp., subsequently increasing to 10 amp. as determined by the resistance.

In such examples as have been presented thus far, the magnetic action of only one coil has been considered. The constant-linkage theorem, however, proves particularly valuable in the analysis of more complex systems of two or more mutually-interlinked circuits. A transformer is an excellent example for analysis.

Consider first the transient behavior resulting from direct-current in the windings of the transformer of Fig. 4. The following constants are necessary:

L_1 = primary self-inductance
L_2 = secondary self-inductance
M = mutual-inductance.

The resistance of the windings is neglected.

In general, the primary flux linkages are:

$$\psi_1 = L_1 i_1 + M i_2$$

and the secondary linkages

$$\psi_2 = L_2 i_2 + M i_1$$

Suppose now that with the secondary switch S_2 closed and no flux in the core a current of i_1 amperes is set up in the primary. What will be the value of the induced secondary current? The original secondary linkages were zero and must remain so; *i.e.*,

$$\psi_2 = 0 = L_2 i_2 + M i_1$$

or

$$i_2 = -\frac{M}{L_2} i_1$$

Now, instead of zero initial flux linkages in the secondary, let the flux due to a current i_1 in the primary be established in the core before the switch S_2 is closed. Then, when S_2 is closed, the secondary linkages will be simply

$$\psi_2 = M i_1$$

since no secondary current exists.

Let the primary circuit now be opened. The secondary circuit must maintain its value of linkages ($M i_1$), and a current must be set up such that

$$\psi_2 = M i_1 = L_2 i_2$$

from which

$$i_2 = \frac{M}{L_2} i_1$$

quantitatively the same as before, but opposite in sense.

Suppose, though, instead of merely breaking the circuit of the primary that the primary current be reversed from i_1 to $-i_1$. As before, the secondary linkage must be

$$\psi_2 = M i_1$$

which is also equal to

$$\psi_2 = L_2 i_2 - M i_1$$

consequently

$$i_2 = 2\frac{M}{L_2} i_1$$

Such examples indicate the extremely simple analysis effected by the use of the constant-linkage theorem. Yet, the switching of direct current may seem a bit abstract and impractical. Nevertheless such an analysis of direct-current transients explains clearly why the low-resistance secondary circuit of a current transformer follows faithfully the variations in current in the primary no matter how irregular may be the wave shape, assuming of course that the iron remains unsaturated.

Continuing the investigation of the transformer, let the primary battery and reversing switch in Fig. 4 be replaced with a source of sinusoidal voltage, as indicated in Fig. 5.

With the secondary open-circuited the primary current will be simply the magnetizing current.

$$E \sin \omega t = L_1 \frac{di_1}{dt}$$

or

$$i_1 = -\frac{E}{\omega L_1} \cos \omega t = -I_m \cos \omega t$$

If now the secondary be suddenly short-circuited by switch S_2 at a time when the flux in the core is zero, the initial secondary linkages are zero and must remain zero. Therefore

$$\psi_2 = L_2 i_2 + M i_1 = 0$$

$$i_2 = -\frac{M}{L_2} i_1$$

In the primary, current must flow to satisfy the necessary relation that the induced voltage equals and opposes the impressed voltage: *i.e.*,

$$\frac{d\psi_1}{dt} = E \sin \omega t$$

or

$$\psi_1 = -\frac{E}{\omega} \cos \omega t$$

$$= L_1 i_1 + M i_2$$

$$= L_1 i_1 - \frac{M^2}{L_2} i_1$$

from which

$$i_1 = -\frac{\frac{E}{\omega} \cos \omega t}{L_1 L_2 - M^2} L_2$$

Introducing the term coefficient of coupling, defined as

$$K = \frac{M^2}{L_1 L_2}$$

the expression for primary current becomes

$$i_1 = -\frac{E}{\omega L_1} \frac{\cos \omega t}{1 - K^2}$$

or, in terms of the magnetizing current,

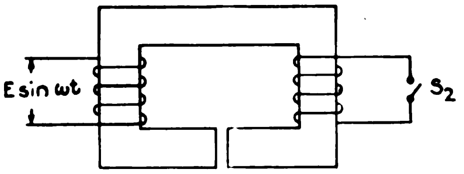
$$i_1 = -I_M \frac{\cos \omega t}{1 - K^2}$$

The secondary current is

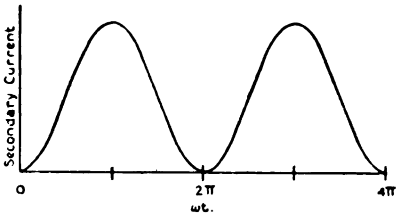
$$i_2 = -\frac{M}{L_2} i_1$$

$$= \frac{M}{L_2} I_M \frac{\cos \omega t}{1 - K^2}$$

Thus, in both the primary and the secondary the current resulting from a short-circuit occurring at the instant of zero flux consists only of a sinusoidal term.



(*a*). Elements of circuit



(*b*). Secondary short-circuit at maximum linkages

Fig. 5. Transformer Circuit Supplied by a Sinusoidal Voltage

If, however, the instant of short-circuit corresponds to maximum flux in the core the initial secondary linkages which must persist are

$$\psi_2 = M I_M$$

Hence, for the secondary after the short-circuit,

$$M I_M = L_2 i_2 + M i_1$$

and for the primary

$$\psi_1 = L_1 i_1 + M i_2$$

The secondary current is

$$i_2 = \frac{M I_M - M i_1}{L_2}$$

giving for the primary linkages

$$\psi_1 = L_1 i_1 + \frac{M^2}{L_2} (I_M - i_1)$$

And, as before

$$\frac{E}{\omega} \cos \omega t = L_1 i_1 + \frac{M^2}{L_2} (I_M - i_1)$$

from which

$$i_1 = \frac{\frac{E}{\omega} \cos \omega t - \frac{M^2}{L_2} I_M}{L_1 - \frac{M^2}{L_2}}$$

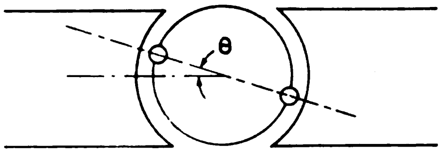
$$= I_M \frac{(\cos \omega t - K^2)}{1 - K^2}$$

For the secondary,

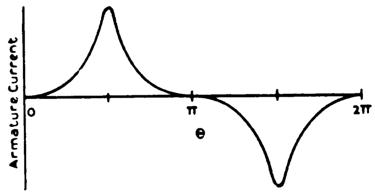
$$i_2 = \frac{MI_M}{L_2\,(1-K^2)}\,[1-\cos\omega t]$$

Thus, the short-circuit current consists of a direct-current term and a sinusoidal term, the direct current being present in order to hold constant the initial value of linkage.

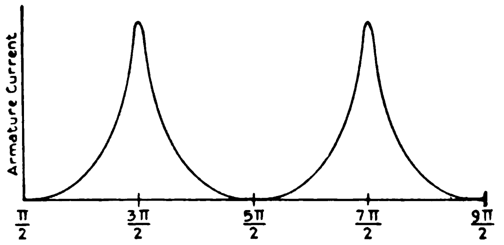
The theorem of constant linkages may also be applied profitably to rotating machines. Consider an elementary alternator (Fig. 6) with stationary field poles and a revolving one-turn armature. Let the armature be short-circuited at a time corresponding to $\theta = 0$, thereby giving zero flux linkages in the closed circuit. As the armature rotates, the initial value of zero linkages must be maintained. Thus, when the coil is in position $\theta = \frac{\pi}{2}$ sufficient current must flow to oppose the normal flux, forcing it into the leakage paths. A fourth of a revolution later the armature current must again be zero; and when $\theta = \frac{3\pi}{2}$ the current has a maximum value equal to that for the $\pi/2$ position, but opposite in direction.



(a). Space diagram



(b). Short-circuit at zero linkages



(c). Short-circuit at maximum linkages

Fig. 6. Alternator with Single-turn Armature and Stationary Poles

Suppose, however, that the short-circuit occurs at maximum flux linkages, *i.e.*, when $\theta = \pi/2$. These linkages can not change as the coil continues to rotate so that current variation must follow. The resultant current must always be in the same direction in order to hold the original linkages, and will have its maximum value when $\theta = \frac{3\pi}{2}$.

Thus, alternator short-circuit current computed by the use of the constant-linkage theorem is seen to be solely a function of the relative position of armature and field. That is, after short-circuit the current may be analyzed, not as a function of time, but rather of position. The armature may be stopped, so to speak, at any point, and the existing armature current analyzed; the armature may then be turned to a new position and the new current necessary to maintain the initial linkages determined. Or, in brief, the linkage theorem analysis reduces the short-circuit to a geometrical function. The fact that the armature position varies with time is only of secondary importance.

A similar analysis may be applied to the field circuit which, in ordinary practice, is effectively short-circuited by the low-resistance armature of its exciter. As the main flux is distorted and forced by the armature current into the leakage paths of high reluctance much more than normal current must flow in the field windings in order to maintain its original number of linkages. Hence, a field current value may be worked out corresponding to each armature position following short-circuit.

Likewise a short-circuit torque analysis may be made. At any position of the armature the energy stored in the field and armature circuits is a function of the position angle θ. Neglecting saturation, that energy is

$$W = \frac{1}{2}\,\psi_a\,i_a + \frac{1}{2}\,\psi_f\,i_f$$

where ψ_a represents the constant armature linkages and ψ_f the constant linkages of the field.

Since all energy changes subsequent to short-circuit must come from mechanical power input, the torque is simply the variation of the energy with position; or, the instantaneous electromagnetic torque during short-circuit is

$$T = \frac{dW}{d\theta}$$

$$= \frac{1}{2}\left(\psi_a\frac{di_a}{d\theta} + \psi_f\frac{di_f}{d\theta}\right)$$

which is seen to be proportional to the slope of the armature and field current-time curves.

Similar reasoning applies to a polyphase alternator. At the moment of short-circuit the flux of the main field poles is caught, so to speak, and held by the armature conductors, giving a replica of the main-pole flux attached to the armature. The rotor, of course, maintains its poles, and accordingly two systems of poles moving relatively to each other result. When the rotor poles are at the position corresponding to the moment of short-circuit, the armature and field currents are those existing before the start of the transient. At a time 180 electrical degrees, or one half-cycle, later the rotor and armature poles again coincide, but are opposite in sense; yet constant linkages must be maintained in each, and maximum values of current result. Thus one or more phases of the machine will have a direct-current component in addition to the alternating-current components. Obviously the stationary field held by the armature must induce in the rotor windings a current of normal frequency. This alternating component of rotor flux in turn induces in the armature a second-harmonic current. Higher harmonics are negligible, usually, because of high reactance to the high frequency. Hence, the general form of the transient phase current in a machine subjected to a three-phase short-circuit is a wave made up of direct-current, fundamental, and second-harmonic components.

Naturally, the resistance of the windings will cause the current to diminish to a steady-state value as fixed by the field excitation and machine constants. Still, the method of analysis explains the components of the transient, and, from the constants of the machine, predicts their magnitudes with reasonable accuracy.

The induction motor or generator, when short-circuited, is another excellent example with which to illustrate the value of the linkage theorem. The induction generator was at one time proposed for quite general use in place of synchronous generators, the underlying thought being that short-circuit problems would thereby be mitigated. The faulty reasoning was based on the erroneous idea that the heavy transient short-circuit currents of an alternator could not exist in an asynchronous machine since the latter has no external source of direct-current field excitation. Sustained short-circuit currents of course can not be maintained by an induction generator, but transient currents of the same order of magnitude as those in an alternator will follow a short-circuit. A consideration of the flux linkages, with the stipulation that they remain constant after short-circuit, leads to a sound quantitative as well as a qualitative solution.

An asynchronous polyphase machine, externally driven, acting as a generator draws its exciting current from the lines. The flux in the machine is rotating at synchronous speed with respect to the stator and is at all times linked with the windings of one or more phases. At the instant of short-circuit the flux occupies a definite position on the rotor and is linked with short-circuited armature conductors in one or more phases. Or, by the action of the closed armature circuits, the flux is effectively caught at its position in space and held, fixed to the stator. Likewise, the flux linked with the rotor remains constant and continues to rotate with it. Thus two sets of closed circuits maintaining constant linkages continue to rotate relatively to each other. At the position corresponding to the instant of short-circuit the armature currents will have the values existing just prior to the short-circuit, *i.e.*, load current and exciting current. One half-cycle later the stator and rotor magnetomotive forces are opposing each other and the fluxes are forced into the leakage paths, resulting in maximum current. The phase currents thus will have, in general, a direct-current component in addition to the alternating components.

Such investigations indicate the type of analysis made possible through the use of the theorem of constant linkages. Complete studies(5) of short-circuit problems in rotating machinery have been made by this method and the excellent agreement between theory and test demonstrates the real value of the theorem far more conclusively than the casual survey made here.

Finally, then, a few concluding remarks on the scope and limitations of the theorem are appropriate. The examples presented here indicate the sort of problem readily analyzed on the basis of constant linkages, and in each the tacit assumption of zero resistance was made for the determination of the initial transient. The resistance was later treated as a decrement factor to give to the examples a practical significance. The initial transient thus computed is actually in error through neglect of resistance, but usually in a very small way. Criticism has been directed against the theorem for that reason and has been valuable, therefore, in stressing the limitations implied in neglecting resistance. Still, what engineering calculation does not involve simplifying assumptions? Even computations based on Ohm's law are not strictly rigorous inasmuch as resistance is generally assumed to be constant, whereas actually its variation with temperature may be relatively large. Likewise, in many electrical problems the iron circuit involved is often assumed to have a straight-line saturation curve. Obviously, this assumption may lead to serious error. Yet, such simplifications are commonly used in order to obtain solutions to otherwise hopelessly complicated problems. In each instance engineering judgment is the principle governing the use of such assumptions. Similarly the linkage theorem must be employed with discretion.

However, proper use of the principle of constant linkages can lead to good agreement between theory and experiment, while the corresponding analysis of the physical problem has an appealing directness and clarity. Consequently, the theorem should not continue as a virtually esoteric concept. Nor should the theorem be withheld from students because of its limitations, for its inherent advantages are too many. Therefore, if any should here learn of the constant linkage theorem for the first time and find thereby satisfaction in the simplicity and clarity effected by its use then the object of this article will have been achieved.

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(5) "Short-circuit Current of Induction Motors and Generators," by R. E. Doherty and E. T. Williamson, *A.I.E.E. Trans.*, 1921, p. 509.

"Synchronous Machines—III (Torque-angle Characteristics Under Transient Conditions)," by R. E. Doherty and C. A. Nickle, *A.I.E.E. Trans.*, 1927, p. 1.

"Short-circuits of A-c. Generators—II," by C. M. Laffoon, *A.I.E.E. Trans.*, 1924, p. 721.

"Short-circuit Currents of Synchronous Machines," by R. F. Franklin, *A.I.E.E. Trans.*, 1925, p. 420.

The Effect of Series Capacitors Upon Steady-state Stability of Power Systems

Maximum Power Depends Upon Voltage Drop, Length, and Frequency of Line—Series Capacitors Reduce Voltage Drop—Demonstration That They Also Increase System Stability—Numerical Examples

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(Abstract of Graduate Thesis (1929), Mass. Institute of Technology, by the authors and H. S. Muller)

EARLY laboratory work in electricity has demonstrated that electric circuits carrying alternating currents of constant frequency could be made to have the same overall characteristics as if a unidirectional source of potential were applied. A familiar case of this nature exists when a series capacitor is connected to an inductive circuit and the capacity so adjusted that the sum of the capacitive reactances is equal to the sum of the inductive reactances. Under this condition the resultant reactance is zero, the resultant impedance is minimum and equal to the combined resistance of the circuit. The current and active power are therefore maximum, and limited only by the circuit resistance.

Since a-c. transmission of power came into vogue, it has become known that the inductive reactance of any system plays a very definite role in the ability of that system to take on additional load or to withstand disturbances due to short circuits, dropping sections of line, etc.

The maximum amount of power in kilowatts which can be transmitted over a given line (without terminal transformers) can be expressed (1) as

$$P_R\,(\max) = \frac{E_R}{1000}\left(\frac{E_S}{\sqrt{R_o^2+X_o^2}} - \frac{lRE_R}{R_o^2+X_o^2}\right) \qquad (1)$$

where E_S and E_R are the sending (generating) and receiving (load) voltages, respectively and R, R_o, and X_o are determined by

$$l\,(\mathrm{R}+j\omega L) = R_o + jX_o \qquad (2)$$

where R = resistance of line in ohms per wire mile
L = inductance of line in henries per mile
$\omega = 2\pi f$ (f = frequency in cycles per second)
R_o = overall resistance of line in ohms
X_o = overall reactance of line in ohms
l = length of line in miles

Neglecting R_o^2 in Equation (1) whenever it appears in the expression $R_o^2+X_o^2$,

$$P_R\,(\max.) = \frac{E_R}{1000}\left(\frac{E_S}{X_o} - \frac{R_oE_R}{X_o^2}\right) \qquad (3)$$

This gives a very close approximation since R_o is usually less than 10 per cent of X_o.

In conjunction with terminal transformers the power limit of the line in kilowatts is

$$P_R\,(\max) = \frac{E_R}{1000}\left(\frac{E_S}{X_o+X_T} - \frac{R_oE_R}{X_o^2}\right) \qquad (3)$$

where X_T is the combined reactance of sending-end and receiving-end transformers.

Hence the maximum power which any line is able to transmit depends mainly upon three factors: (1) voltage, (2) length, and (3) frequency. For fixed frequency and length of line, therefore, any improvement which would offset the inherent inductive reactive of the lines, and that of the terminal transformers as well, would mean a definite gain in maximum power. The greater this theoretical steady-state power limit, the more likely the line itself is able to withstand operating disturbances. Series capacitors can be designed to compensate for all or any part of the overall system reactance. The partial or complete neutralization of line and transformer reactance by series capacitors presents a method, conveniently applicable to existing or proposed systems, by which an increase in transmitted power is made possible.

The first application (2) of this scheme at commercial frequencies was for voltage regulation, and has been in service at the Ballston Substation of the New York Power & Light Corp. since March, 1928. Here three single-phase capacitors, each rated 415 kv-a., were placed in series with the line conductors of a 33-kv. circuit which connects Amsterdam and Ballston (N. Y.). A close-up of the protective equipment mounted on a capacitor of this rating is shown in Fig. 1.

Because the series capacitor carries the line current the drop across it is directly proportional to the line current. To be satisfactory, the protective equipment must take care of two possible abnormal conditions: (1) a short circuit of the line on the load side (which would impress line voltage on the capacitor bank) and (2) a dielectric failure in the capacitor itself (which would allow the load current to arc through the faulty section.) For protection against these conditions, there has been developed a combination of special sphere gap and a shunting contactor actuated by a high-speed mechanism. An application of this equipment appears in Fig. 2. For installations on medium or low-voltage lines, the capacitor has been protected by a similar scheme utilizing a sphere gap and a small shunt contactor.

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(1) O. G. C. Dahl: *Notes on Electric Circuits*, M.I.T., 1928.

(2) "And Now the Series Capacitor," by T. A. E. Belt, Editorial, GENERAL ELECTRIC REVIEW, August, 1928.

The protective equipment connected as shown in Fig. 2 has been developed so that it automatically short circuits the capacitor when the voltage rises to 150 or 200 per cent of its rated value. (3) The abnormal current may be due to a steady overload or to a short-circuit on the load side of the capacitor. Should either of these conditions occur, a sphere gap across the capacitor is set to sparkover, thus causing the breaker to close and to short circuit the units. In addition to protecting the capacitors, this short-circuiting feature in effect serves to introduce the line reactance into the system under fault conditions thereby tending to reduce the short-circuit current. The high-speed mechanism can operate (*i.e.*, completely take the capacitor off the line) in four to eight milli-seconds.

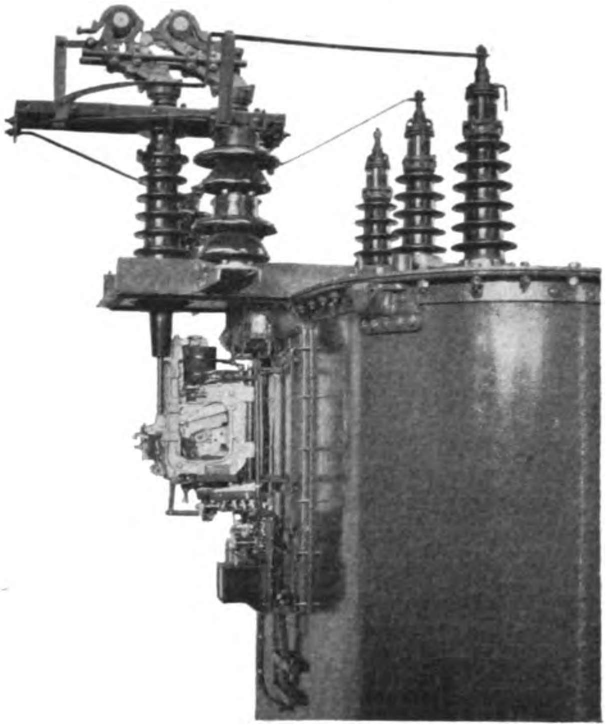

Fig. 1. Protective Mechanism Mounted on 415-kv-a. Series Capacitor for 33-kv. Transmission-line Regulation

Series capacitors as now built consist of a number of parallel sections. Should any one of these sections fail, the line current would be shunted through this defective unit and the compensating reactance value of the capacitor eliminated. To prevent any individual failure from causing trouble, the apparatus is so arranged that an unbalance of voltage will operate an impedance relay which in turn closes the high-speed circuit breaker. If a fault on the line has occurred, its clearance will cause the protective mechanism to automatically reinsert the capacitors in the transmission-line circuit. This is effected by an undercurrent relay actuated by a current transformer in series with the breaker.

The operating results of series capacitors with similar protective mechanisms which have already been utilized in commercial installations are very promising.(4) These were installed to completely neutralize the line inductive reactance for the purpose of improving the voltage regulation and control of load distribution over loop circuits. While series capacitors have so far been applied only to relatively short transmission lines operating at 33 kv. or below, the results there obtained promise as favorable a field of usefulness in the transmission of power over long distances.

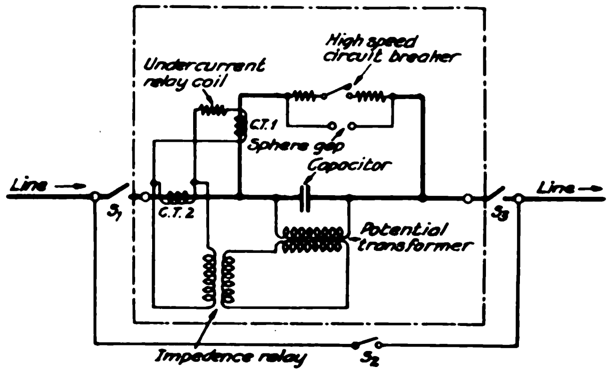

Fig. 2. Essential Diagram of Series Capacitor and Protective Equipment

In order to determine what effects series capacitors would have upon the power available and the stability of a 250-mile transmission line operating at 110 kv., a theoretical study was made of two representative systems, one to which series capacitors were applied to compensate for inductive reactance, Fig. 3(a), and the other without such capacitors but with a synchronous condenser, Fig. 3(b). Otherwise the two systems are identical. In order to compensate for the inductive reactance of the line and terminal transformers, Fig. 3(a), it was necessary to insert a series capacitive reactance of 263 ohms, or 10.07 microfarads per phase at 60 cycles. A tabulation of the circuit constants will be found in the Appendix. An effort was made to use the typical values throughout in order to correspond with general operating practice. Obviously, this should give a basis that is true to operating conditions upon which to compare the system characteristics.

A curve defining the stability of a system (Fig. 4) gives the relation between the power at the point where the additional load is switched on and the voltage at that or some other point in the system. In determining the stability curve, it is evident that the characteristics of all parts of the system must be taken into account. This includes the characteristics of lines, transformers, generators, condensers, and loads. Also, in making an analysis under the assumption of constant-air-gap flux in the synchronous machinery, as was done in this case, the steady-state condition under very gradual changes of load are represented. When additional load is switched onto a system, it will be accompanied by a drop in voltage at all points of the system. This is due to the fact that commercial loads are either unity power-factor loads or inductive loads, and hence the current taken must produce a drop in voltage since the characteristics of the system itself (*i.e.*, of line and transformers) are usually inductive. This is also true if the overall characteristics of the line and transformers are neither inductive nor capacitive, *viz.*, the neutralized reactance circuit condition. Therefore, in order to make it possible to switch additional load onto a system, the power-voltage characteristic must be such that a drop in voltage is accompanied with an increase in power. If this be not the case, additional load cannot be switched on because as soon as the line has a tendency to carry the additional load, the voltage will drop. Since this drop will be accompanied by a decrease in power, there is consequently no tendency to pick up the additional load.

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(3) "Series Capacitors," by M. I. Alimansky; presented to Local Section A.I.E.E. Pittsfield, Mass., Feb. 18, 1930.

(4) "The Series Capacitor Installation at Ballston, N. Y.," by B. K. Shelton, GENERAL ELECTRIC REVIEW, Vol. 31, No. 8, August, 1928, p. 432.

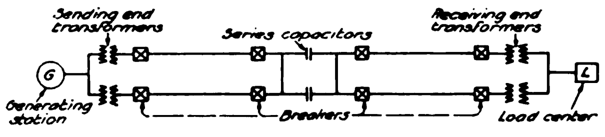


Fig. 3(a)

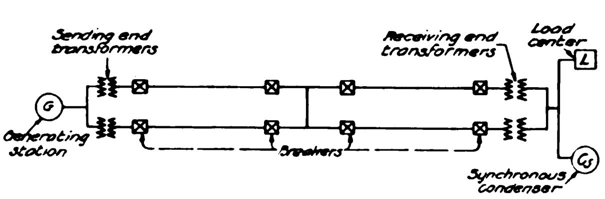


Fig. 3(b)

Fig. 3. Typical Connections for a Transmission System with Series Capacitors or Synchronous Condenser

In the power system under consideration, the details of which are outlined in the Appendix, stability under very gradual changes of load will be maintained for the value of 50,000 kw. initial load, as shown in Fig. 4. A tabulation comparing the system with and without series capacitors, for this and additional load, is given in Table I.

It is to be remembered that these values do not represent maximum power values in either case, but the maximum values which can be switched on for that amount of initial load. Maximum power limits are therefore even higher than is indicated by item (3) in Table I, since both remain in synchronism at that initial load. However, it is evident that the system without series capacitors has practically reached its power limit at 53,000 kw.

Now to maintain 100 per cent voltage at the load end of the series-capacitor system, one alternative would be to allow the sending-end voltage E_S to rise by increased excitation to whatever value necessary to reach 100 per cent E_R. From Fig. 4, for an initial load of 50,000 kw. this value of E_S is 106.5. This would not seem objectionable in the case of an isolated hydro-station in which the circuits do not radiate to other load centers. If it were desirable to maintain 100 per cent voltage at both ends of the system, generation could take place at this voltage; and transmission at 106.5 per cent for example could be effected by adjustable voltage ratios on the sending-end transformers. The important point is that here an alternating-current system has been made to have direct-current characteristics insofar as transmission of energy is concerned. It is found in this case that 6.5 per cent of the rated system voltage represents the *IR* drop in transmitting 50,000 kw. over two parallel 250-mile circuits at 110 kv. Since the *IZ* drop in the line is now a minimum, no quadrature kilovolt-amperes are necessary from synchronous equipment except in case it is found economical to correct for the lagging component of load in order to reduce copper losses. The line drop, governed only by the circuit resistance, can be adjusted to maintain 100 per cent load voltage by either of the methods that have been suggested.

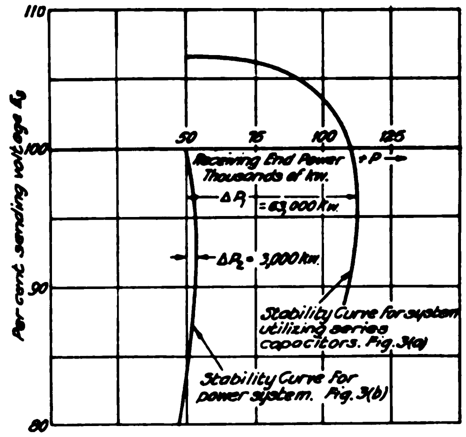


Fig. 4. Comparison of System Stability Under Very Gradual Changes of Load

TABLE I

	Series Capacitors Installed in System	Without Series Capacitors
(1). Initial load transmitted..	50,000 kw.	50,000 kw.
(2). Additional load available.	63,000 kw.	3,000 kw.
(3). Total power transmitted.	113,000 kw.	53,000 kw.
(4). Additional load based on initial..................	126.0 %	6.0 %
(5). Sending end voltages at initial load..............	106.5 %	100.0 %
(6). Sending end voltages at additional load..........	96.0 %	92.0 %
(7). Receiving end voltages at initial load..............	100.0 %	100.0 %
(8). Generator field currents..	143.0 amp.	113.0 amp.

Present installations of series capacitors have demonstrated the value of decreased line drop by their improvement of voltage regulation, and at the same time the benefits of increased power limits are available on the overloaded systems. Practically then, the advantages of direct-current transmission can be realized by the use of series capacitors without sacrificing the desirable ability to transform voltages on present alternating-current networks.

APPENDIX

The data for the systems analyzed in this article are as follows:

Generating Station: Hydro-electric station of 120,000 kv-a., consisting of four 30,000-kv-a. 13,200-volt 60-cycle 0.8-p-f. salient-pole machines. Speed, 150 r.p.m. Number of poles, 48. Short-circuit ratio, 1.0 (normal conditions). Armature-leakage reactance, 23 per cent. Transient reactance, 30 per cent.

Synchronous Condenser Installation: The total installation is 60,000 kv-a. In determining the system stability, the same machine charts based on generator data were utilized for this installation.

Transmission Line: The configuration of conductors for this double-circuit three-phase line is practically hexagonal, with conductors for one phase (a) on upper left, (b) on middle right, and (c) on lower right. The spacings are a—c = 34.7 ft., b—c = 13.0 ft. and a—b = 32.3 ft.

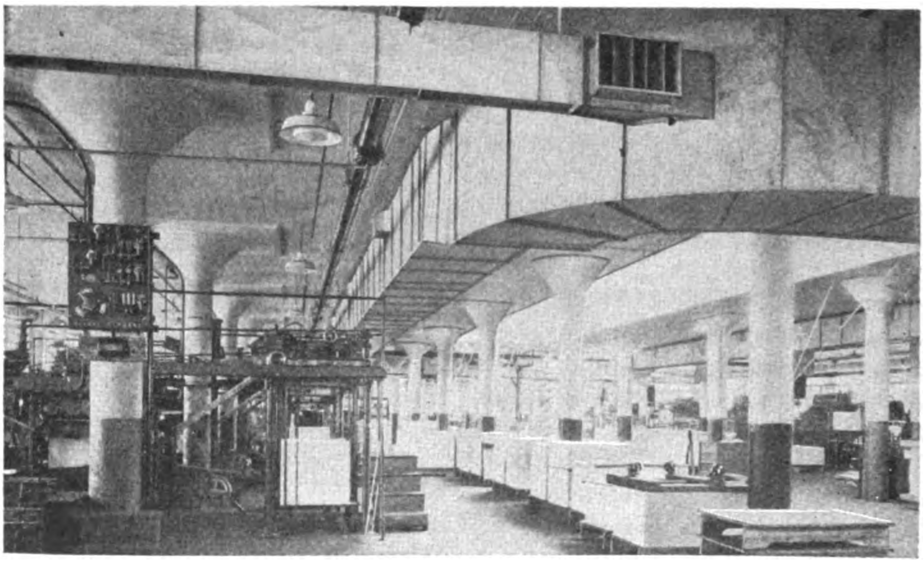
Overall length = 250 miles
Size of conductors = 795,000 A.C.S.R.
$R = 0.117$ ohm per wire mile
$X = 0.831$ ohm per wire mile
$G = 0.100 \times 10^{-6}$ ohm per wire mile
$C = 0.01382 \times 10^{-6}$ ohm per wire mile

Transformers: The sending- and receiving-end transformers are similar, the total installation at each end being 120,000 kv-a. All transformers are connected delta on the low side and Y on the high side with the neutral of the Y solidly grounded in each case. $R = 0.5$ per cent; $X = 12.0$ per cent; Iron Loss = 0.6 per cent; Copper Loss = 0.5 per cent; Magnetizing Current = 5.0 per cent.

Capacitors: Six single-phase capacitors are utilized, each phase unit having a value of capacitive reactance equal to the combined per phase values of inductive reactance of each line and its terminal transformer. The time required for the protective equipment to function (to completely shunt the capacitor off the line) after a fault occurs, is between 0.004 and 0.008 sec. After the fault is cleared the protective devices place the capacitor back in series with the line in 0.25 sec.

Load: Initial load, 52,100 kv-a. at 96 per cent power-factor.

A "Motorized" Printing Plant



A group of offset presses in a lithographing plant whose entire output is printed, folded, and bound by electrically-driven machinery

Ultra-violet from the Sun and from the General Electric Sunlamp

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> *The present article deals with sunlight and artificially produced ultra-violet light in connection with therapy. The characteristics of the new sunlamp and the lamp itself are described and the results attained in curing rickets are given.*
> —EDITOR

(1). Sunlight and Therapy

SUNLIGHT is an essential factor in animal and plant life, and studies of its effects, as well as those of artificial sources of radiant energy, have produced an extended literature on the subject.(1) The ultra-violet region of the spectrum has received the greatest attention and is considered responsible for the beneficial results obtained in the prevention and cure of rickets,(2) and in the treatment of certain forms of tuberculosis.(3) The term ultra-violet is often used for a region of the spectrum which is not clearly defined, but for convenience we may divide the spectrum into three major portions: the ultra-violet below 4000 Ångstroms; the visible from 4000Å to 7000Å; and the infra-red from 7000Å to a rather indefinite limit beyond 30,000Å. The ultra-violet region, effective for therapeutic purposes, may be further limited as indicated by the following considerations. Energy from the sun of wavelengths shorter than 2900Å does not reach the earth's surface even under the most favorable conditions.(4) Thus, we are able to fix a lower limit for the wavelength of beneficial energy from the sun. Opinions may differ somewhat on the upper limit of beneficial action, but it has been reported that rachitic rats(5) and chickens(6) exposed to the radiation from the sun and quartz mercury arc through window glass showed no improvement during the course of the experiments. The transmission of window glass rises rapidly for wavelengths longer than 3200Å. Thus, on the basis of the work to which reference has been made, we may consider that the energy of sunlight which is effective in the cure of rickets lies between 2900Å and 3200Å.

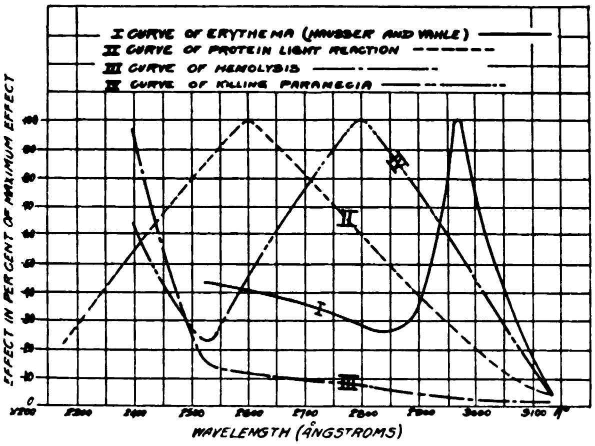

Fig. 1. Biological Effects of Light. From Sonne: *Archives o Physical Therapy 10,239* (1929)

Maughan, in his work on chickens, concludes that the energy from a quartz mercury arc which is effective in the cure of rickets occurs between the wavelengths 3130Å and 2650Å with the maximum effect at 2968Å.

Hausser and Vahle(7) have determined a curve showing the relation between wavelength and erythema, or sunburn, produced by equal amounts of energy. They find maximum effectiveness slightly below 3000Å, practically no effect above 3100Å, a small effect at 2800Å with a slight rise to 2600Å. We may then subdivide the broad ultra-violet region of the spectrum into ranges effective for particular reactions:

3200Å to 2900Å: Effective in producing erythema and cure of rickets by sunlight.
3200Å to 2800Å: Most effective range for producing erythema by artificial sources.

Dr. Carl Sonne,(8) of the Finsen Institute, Copenhagen, has discussed the biological effects of ultra-violet rays in an interesting paper and the curves reproduced in Fig. 1 are from that source. The curves illustrate the relative effects of different parts of the ultra-violet spectrum on several biological reactions. As an example, the wavelengths close to 3000Å are most effective for the production of erythema, while these same wavelengths have very little effect on the hemolysis of the blood.

The foregoing paragraphs indicate that a detailed knowledge of the spectral distribution of any source of radiation used for therapeutic purposes is essential for any satisfactory explanation of the reactions involved.

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(1)"The Physiological Effects of Radiation," by Henry Laurens, *Physiological Reviews 8*, No. 1, Jan., 1928. Contains extensive bibliography.

(2)K. Huldsckinsky *Deutsch. med. Wochenschr. 45*, 712 (1919).
Hess and Unger: *J. Am. Med. Asso. 77*, 39 (1921).
Hess and Weinstock: *J. Am. Med. Asso. 70*, 687 (1923).
Tisdall and Brown: *Proc. Soc. Exper. Biol. Med. 24*, 446 (1927).

(3)E. Mayer: "Clinical Applications of Ultra-violet Radiation and Sunlight."
S. H. Watson: *Archives of Phys. Therapy 10*, 451 (1929).

(4)Fabry and Buisson: *Astrophys. Jr. 64*, 297 (1921).

(5)Tisdall and Brown: *Am. J. Diseased Children 34*, 742 (1927).

(6)G. H. Maughan: *Am. J. Physiology 87*, 381 (1928).

(7)Hausser and Vahle: *Strahlentherapie*, Vol. 13. 59, (1921-1922).

(8)*Archives of Phys. Therapy, X-ray Radium 10*, 239-252 (1929).

It is our purpose to present the data at present available for the General Electric Sunlamp and the Type S-1 lamp and to compare the ultra-violet energy from the lamp and from sunlight.

(2). Irradiation Units

It is a convenient method, but hardly an accurate one, to compare the spectra of different sources used for some specific irradiation by the amount of energy between fixed wavelength limits. Thus, in dealing with erythema the limits 2800Å to 3200Å have been used recently as defining the region effective for production of erythema. The objection to this is that the erythema effect is rather sharply defined around its maximum point, and the effectiveness of energy depends largely upon how closely it comes to this point of highest efficiency. Also, all of the familiar sources of energy, such as the sun, the various arcs, and the Sunlamp, give either discontinuous or unbalanced distributions of energy in this region, and an accurate evaluation of these sources requires taking into consideration the wavelength relation between energy and erythema factors.

The erythema factors here used are taken from the published work of Hausser and Vahle, who are more often quoted than anyone else, and whose work has received verification from Sonne and others. In Fig. 2 the solid curve is the original curve published in 1921, and this curve will be used in the present article. The later data given by the broken curve are in agreement from 2700 to 3150Å, and this is the only region that interests us at present because the two energy sources considered later do not give energy of shorter wavelengths than 2700Å. The spectrum of the sun, as observed from sea level, begins at about 2922Å and rises very rapidly at longer wavelengths. The greater part of the energy in the 2800 to 3200Å region lies to the right of the peak of the erythema curve, and obviously the sun will not be so effective as a source of energy as another source having an equal amount of energy located nearer the center of the erythema curve. The spectrum of the G-E Sunlamp in this region is the discontinuous spectrum of mercury vapor, modified by the transmission characteristics of the bulb, and the six lines and groups of lines within the above limits are unevenly spaced and of widely different strengths. The tungsten spectrum in this region is relatively weak, as will be shown later.

We might borrow the methods of the illuminating engineer who has a similar problem in converting energy into terms of light. He is under a handicap that should not reoccur here. The candle, which is historically the first of the illumination units, is entirely arbitrary in size and is without any logical connection to either the c.g.s. system or the British system of units. It seems probable that the study of erythema and the attendant physiological reactions will be extended to wide limits in the near future and be of considerable importance, so that a logical terminology will be needed. On account of the universal use of the electric lamp in one of its many forms for the conversion of energy, it seems evident that the electrical terms for energy are more suitable than the chemical terms now used. Thus "gram calories (15 deg.)" is not nearly so useful a term in connection with an electric lamp as "watts" or "micro-watts," and the latter terms have the further great advantage of being understood by a wider circle of people who are neither electrical engineers, physicists, nor physicians.

On account of the small quantity of energy dealt with in the study of erythema, and other reactions to specific wavelengths, it is suggested that the microwatt be the unit of power, and the other units be derived from this as outlined in Table I. The symbols have the following meanings:

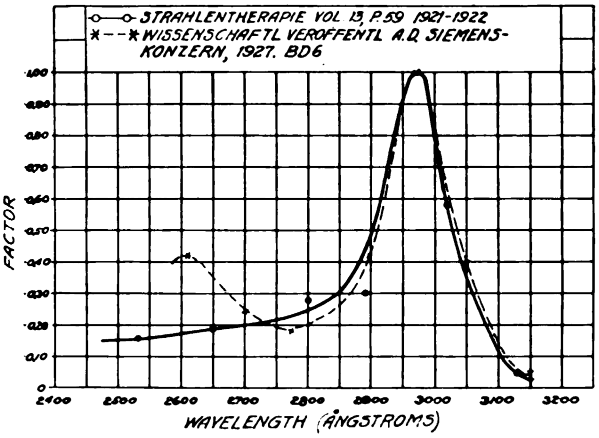

Fig. 2. Erythema Factors by Hausser and Vahle

F = Light flux, in lumens
Q' = Quantity of light: Lumens × hours
E = Illumination in meter-candles
A = Area in square meters
a = Area in square centimeters
w = Solid angles, in steradians
V_λ = Visibility factor at wavelength λ
W = Watts
R = Erythema factor
U = Erythema units
μW = Micro-watts = 10^{-6} watts
T = Time in hours
t = Time in minutes
I = Candles, in illumination
I' = Erythema radiation intensity
E' = Irradiation unit.
D = Dosage unit
λ = Wavelength in Ångstroms (10^{-10} meter)

The various combinations in the Irradiation System corresponding to the lumen, lumen-hour, meter-candle, and candle, have not received distinctive names as yet, although all have perhaps been either used or implied in the literature. Coblentz(9) and others have suggested that the unit of erythema dosage be called the Finsen, in honor of Dr. Finsen, the pioneer in ultra-violet therapy, but this suggestion seems to make it an energy unit unreduced by application of the characteristic curve of the function under consideration. This seems to the writers to stop somewhat short of the fixed and orderly process that is necessary to express irradiation in units as definite and understandable as the entirely similar units of the illuminating engineer. In Fig. 1 the various physiological functions are seen to differ in their relation to wavelength, but the procedure for reducing from energy to each particular irradiation unit is the same. At the point of maximum efficiency of each function the energy is given full value; at other wavelengths the energy is given a value proportional to the height of the characteristic curve. The summation of all energy, so evaluated, is then a measure of the value of the source for the function under consideration.

TABLE I

CORRESPONDING FACTORS IN ILLUMINATION AND IRRADIATION

Nature of Unit	Illumination System	Irradiation System
(1). Quantity Rate	Lumen, $F = \int_o^\alpha W_\lambda V_\lambda d\lambda = \sum W_\lambda V_\lambda$	$U = \int_o^\alpha W_\lambda R_\lambda d\lambda = \sum_o^\alpha W_\lambda R_\lambda$
(2). Quantity Total	Lumen hour, $Q = FT$	$Q' = Ut$
(3). Surface Rate...........	Meter-candle, $E = \frac{F}{A}$	$E' = \frac{U}{a}$
(4). Radiation Rate.........	Candle, $I = \frac{dF}{dw}$	$I' = \frac{dU}{dw}$

The summation of evaluated energy, in microwatts, times the time of exposure, *t*, in minutes, divided by the square centimeters of skin receiving this energy is the suggested measure of dosage

$$D = \frac{U}{a}t = E't$$

The procedure here outlined carries the physical properties to the boundary between the physical and physiological fields; beyond this point the further action must be expressed in physiological terms that are outside of the purpose of this article, but the simpler physical units with their physiological meaning are seemingly a vital step that must precede the more complicated terms that physiology uses.

(3). Radiation from the Sun

The distribution of energy in the sun's spectrum is greatly modified by the filtering action of the earth's atmosphere, and sunlight as observed at the surface of the earth is of a different composition, particularly in the ultra-violet, from the sunlight as it reaches the upper limits of the atmosphere. Our sources of information about this radiation are few in number and not always concordant in results, and it is literally true, that to gain a reasonably complete energy picture of sunshine, we must patch together the work of different men, taking from each that part which seems most accurate, but without having anywhere a sure standard of comparison. In dealing with sunlight the conditions are selected so as to represent a maximum effect in the latitude of the northern United States. From this maximum the effects decrease to zero under different weather conditions; but, as will be shown later, artificial illuminants can compete with the sun in the production of certain useful ultra-violet radiation when the sun is at its best in the middle of summer, and throughout the rest of the year they are superior.

(4). Solar Constant

The sun itself is not constant either in the intensity or the composition of its radiation. Abbot and his co-workers of the Smithsonian Institution have for many years been measuring the intensity and composition of sunlight at Washington, on Mt. Wilson, in California, and at the station at Calama, Chile. From these measurements the average intensity of radiation on a square centimeter of surface just outside the earth's atmosphere is known to be 136 milliwatts. The transmission coefficient for the atmosphere, when the sun is directly overhead and there are no clouds, is about 0.78 for a sea-level station, and therefore the maximum radiation that we can receive is 106 milliwatts (or 106,000μW) per square centimeter of surface normal to the incident energy.

(5). Absorption and Scattering

The changes in the transmission of the atmosphere are large in size and variable in character, and here is the reason for the scarcity of information. The technic of making an analysis of the sun's energy requires equipment, skill, and patience such as few possess, and our sources of information are limited to Abbot for the region from 4000 Ångstroms, the lower limit of the visible spectrum, to 25,000Å in the infra-red. Below 4000Å the work of Fabry and Buisson stands almost alone as a source of information. Forsythe and Christison in their recent article on "Ultra-violet Radiation from the Sun and from Heated Tungsten,"⁽¹⁰⁾ quote unpublished data from Professor George Winchester and Brian O'Brien, on the ultra-violet region, and data from all these workers will be used later.

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(9)Coblentz and Stair, *Bureau of Standards Journal of Research*, Vol. 3, 205, (1929), p. 629.

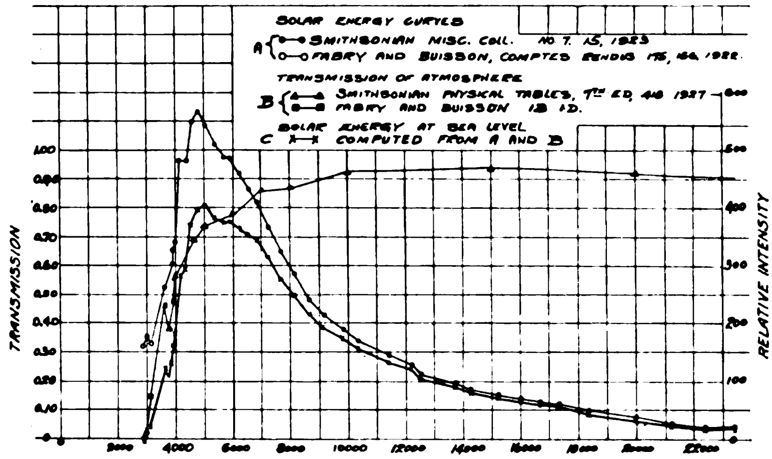

Fig. 3. Solar Energy Curves

The method of finding the effects of the atmosphere without attempting to get physical instruments beyond the limits of the atmosphere is as follows: At frequent intervals throughout the day, the solar spectrum energy is measured, and with each energy measurement record is made of the time so that the relative length of the path through the atmosphere can be computed. A vertical path gives "air mass = 1," and for variations from the vertical, the air mass varies as the secant of the angle. Obtaining the intensities for various air masses and plotting on logarithmic paper the extrapolated curve at air mass zero give the sun's energy before it is filtered by the atmosphere. In the visible region of the spectrum, the change in air mass either with time of day or season of year does not make any great change in the amount of energy received until the air mass reaches a value of two or more. Thus, at 8 a.m. and 4 p.m. with air mass = 2, the light on a normal surface does not differ greatly from the illumination at noon. But in the region around 3100Å, where the sun's energy has a high erythema value, the transmission for air mass = 1 is about 0.1, and for air mass = 2 it is 0.01, and at air mass = 3 it is only one part in a thousand. From this it is evident that the time of day and the season of the year are important factors for erythema radiation.

The foregoing data are for clear skies and smoke-free atmospheres, and for only the direct light from the sun that can be received in a spectroscope or bolometer. The diffused light from a blue sky has undoubted therapeutic effects but of a smaller intensity than sunlight. Clouds, dust, or smoke absorb the ultra-violet readily and thus we are in possession only of data applying to clear atmospheres. There is here an important distinction to be made between visible radiation and radiation around 3000Å. It has been shown that the spectral quality of the total visible radiation received does not differ greatly with the degree of cloudiness. Thus, if to sunshine, with its characteristic yellow hue, we add the characteristic blue from the sky that goes with strong sunlight, the quality of the combination does not differ greatly from the energy composition of light received from an overcast sky. The reason for this stability is that the clouds and the atmosphere scatter the light rather than absorb it and the quality of the light received is thus far more stable than is the quantity.

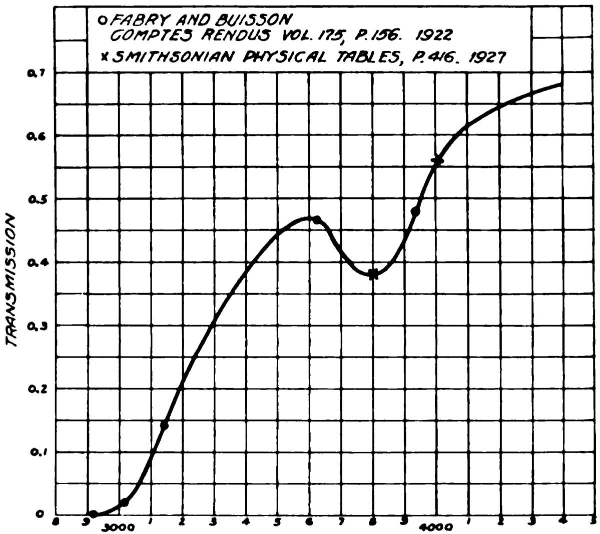

Fig. 4. Transmission Factors of Earth's Atmosphere

In the erythema region the weakening of the sun's spectrum is caused by a true absorption of energy with no reradiation at the same wavelength. Fabry and Buisson have shown rather conclusively that the

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(10) Forsythe and Christison: GENERAL ELECTRIC REVIEW 32, 662 (1929).

oxygen in the upper atmosphere is converted into ozone by the extreme ultra-violet of the sun's spectrum, and this ozone is a very powerful absorber of radiation around 3000Å, and it allows the transmission of one part in one hundred thousand at 2922Å. Below this point, there is practically complete extinction at sea level, and the spectrum of the sun may in this region be beyond our observation for some time to come.

There is some question of the accuracy of all of the existing solar data in the 3000Å region. Thus, Abbot has found the radiation from the sun to be less than the determination of Fabry and Buisson, but the transmission of the atmosphere was computed to be much higher, giving a material increase in radiation reaching the earth's surface. He worked at 2700 meters above sea level, but this should not have occasioned the great difference in results because the ozone that is the apparent absorbing agent is in the upper atmosphere and above both test stations.

(6). Radiation at the Earth's Surface

The temperature of the sun is about 5950 deg. K., according to Fabry and Buisson, who found this to be an average indication in the region around 3000Å. If the energy of the sun came to us unaltered by the atmosphere, it would be fifty times as strong in this region as it is actually received under the most favorable conditions. With the artificially generated ultra-violet energy this strong absorbing action is not present, and it thus becomes possible for us to equal the sun in erythema value with light sources of small wattage and temperature of only 3200 deg. K. in the metal parts of the radiating element.

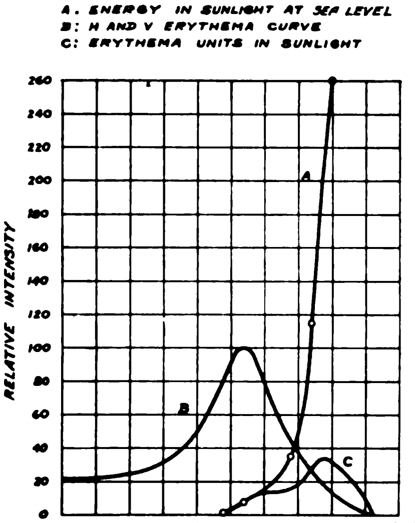

Fig. 5. Erythema Radiation in Sunlight at Noon (Air Mass = 1)

In Fig. 3, Curve A is the spectrum of sunlight as it leaves the sun; B is the curve of transmission of a clear atmosphere at sea level, and C is the maximum spectrum received at sea level. Curves A and B are each derived in part from two different authorities and, from these composite curves, Curve C is computed.

In Fig. 4 the left end of Curve C of Fig. 3 is replotted to a greatly enlarged scale, but even here the vital region around 3000Å is still on too small a scale, and a further magnification is given in Fig. 5 for this region from 2940 to 3100Å. Curve B is Hausser and Vahle's erythema curve, and C is the erythema value in arbitrary units. One point of importance brought out by Curve C is the relatively large effectiveness of wavelength 3100Å while the region below 3000 contributes practically nothing.

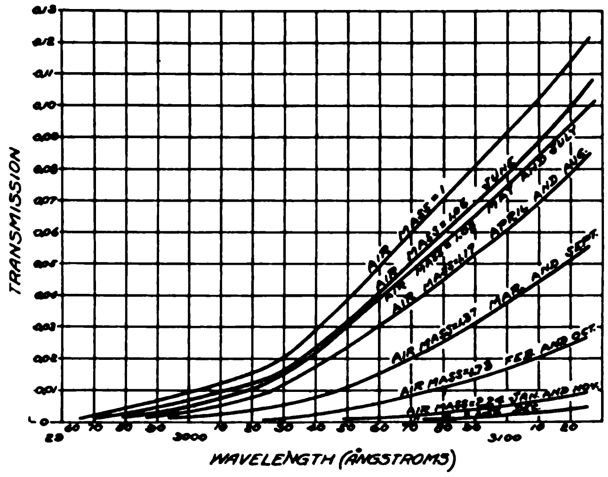

Fig. 6. Transmission of Atmosphere for Erythema Radiation at Noon. Latitude of Schenectady, N. Y.

(7). Yearly Variations

The daily and yearly variations in the erythema effect of sunlight may be approximated for similar atmospheric conditions by a very simple computation. For the latitude of Schenectady, the sun at noon varies from a zenith distance of 19.5 deg. in midsummer to 66.5 deg. in midwinter. No further correction need be made because the human body presents practically normal surfaces to sunlight at all times. If the energy received on a square centimeter of horizontal surface were under consideration, it would be necessary to correct for the foreshortening of this surface in the sun's rays, but not much of the exposed surface of our bodies is in a horizontal plane, and the energy may be considered as falling on a surface always normal to the incident rays.

If the transmission factor for unit air mass is t_1, then for any other mass m the transmission t_m is found from the relation

$$t_m = t_1^m$$

In Fig. 6 the transmissions are computed for every month of the year for the latitude of Schenectady, N. Y., starting with the data of Fabry and Buisson for air mass = 1, and using the above equation for the air masses given on the curves for the various months. It is at once evident that the strength of the erythema rays in December is almost vanishingly small compared with the strength in June, and this computation is borne out by our experience in becoming tanned by sunlight.

The plotted values of total erythema units received in Fig. 7 are of course all maximum values for cloudless skies, and as cloudy skies are more prevalent in winter than in summer the actual difference in the erythema radiation received during the year is greater than shown by the curve, and for the winter months it is practically zero.

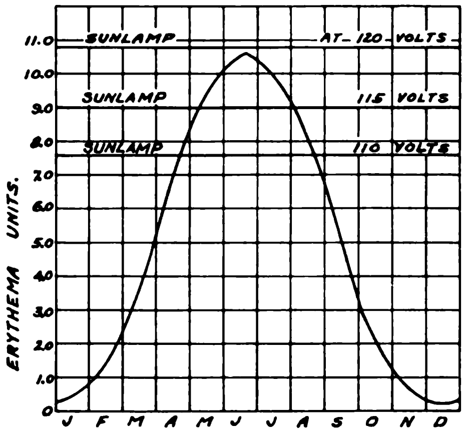

Fig. 7. **Maximum Erythema Values of Sunlight Throughout the Year. Latitude of Schenectady, N. Y.**

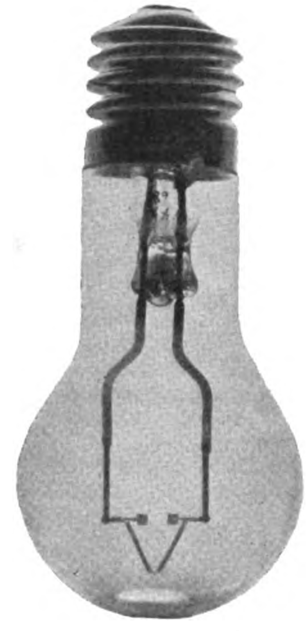

Fig. 8. **The Type S-1 Lamp**

The relative amount of reflected radiation in the erythema region received from the sky has been estimated as from one-quarter to three-quarters of the amount of direct radiation received from the sun, but this phase of the situation has not been given sufficient attention to make available data that can be used with the information already quoted. The highest value, three-quarters of the direct, seems hardly consistent with either the manner in which the energy is absorbed by ozone, or with the known ratio of sky light to direct sunlight. In localities having the overcast type of winter sky prevalent in northern New York, the radiation received from the winter sky must fall far below the figures just quoted, and the additional sky radiation can hardly be sufficient to compensate for the lack of direct radiation.

(8). G-E Sunlamp

This lamp has a number of unusual features that mark it as something new in the way of a source of radiant energy. It is a combination of lamp and ultraviolet generator, and also a combination of an arc and an incandescent lamp. Viewed as an arc it has the further unique feature of starting and operating without the use of any moving parts. Its electrical characteristics are different from other lamps, and as will be noted in detail later, even in its depreciation characteristics it does not follow the normal course of either an arc or an incandescent lamp.

The General Electric Sunlamp (Type S-1 lamp)(11) supplies visible and infra-red energy over the range of wavelengths occurring in sunlight, together with an amount of ultra-violet radiation equivalent to that of maximum sunlight, and extending to somewhat shorter wavelengths. At equal intensities of visible illumination the G-E Sunlamp furnishes about 54 times as much energy effective for producing erythema as the sun. It is because of this difference of relative

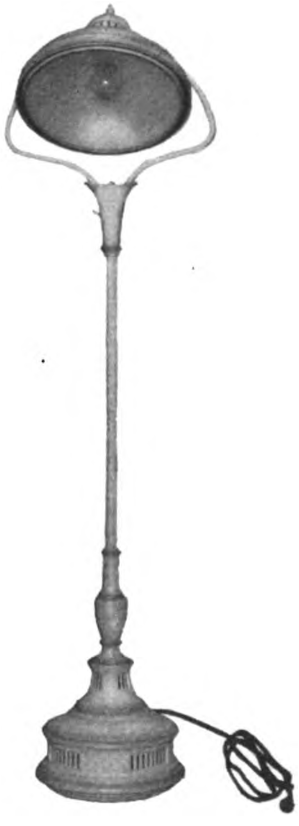

Fig. 9. **The G-E Sunlamp**

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(11) Luckiesh: *Light Magazine*, Jan. (1930).
Preprint, Winter Convention of A.I.E.E., Jan. (1930).

intensity that the beneficial effects of summer mid-sun may be enjoyed at a level of illumination which is not objectionable indoors. Photographs of the General Electric Sunlamp and the Type S-1 lamp are shown in Figs. 8 and 9. The Sunlamp resembles in appearance one of the usual types of floor lamps having a reflector of a diffusing surface of aluminum oxide on aluminum. The light source (Type S-1) radiates energy from two sources: first, from incandescent tungsten filament and electrodes, and, second, from a mercury arc operating in parallel with the tungsten filament. A pool of mercury in the bulb supplies a rising vapor pressure of mercury as its temperature is increased. The incandescent tungsten furnishes energy in a continuous spectrum while the mercury arc contributes a line spectrum extending beyond the spectrum of the incandescent tungsten on the short wavelength side and limited by the absorption of the bulb. In this design the tungsten filament serves as a starting device which functions on turning the switch in the same manner as we turn on our incandescent lamps. A high-reactance transformer, designed particularly for this lamp, is located in the base of the fixture and furnishes the voltage for starting and operating the lamp.

When the circuit is closed on a 115-volt line, the transformer is capable of supplying 33 volts to the filament at a current of nine amperes. This current heats the filament to a temperature at which the electron emission is sufficient to start an arc between the ends of the filament near the electrodes. Then, owing to the geometrical arrangement, the electrodes are heated by electron bombardment and the arc, leaving the filament, plays between the tungsten electrodes. A low pressure of argon gas in the bulb aids in starting the arc, but the character of the arc soon changes to that of mercury as the pressure of mercury vapor rises. When the arc strikes, the total current through the lamp rises to about 30 amp. and the voltage falls to 10 or 12 volts. At this lower voltage the mercury arc carries about 25 amp., and the parallel circuit through the filament about five amperes. The transformer draws about 9.5 amp. at 115 volts, but because of the low power-factor a wattmeter in the primary circuit indicates about 450 watts.

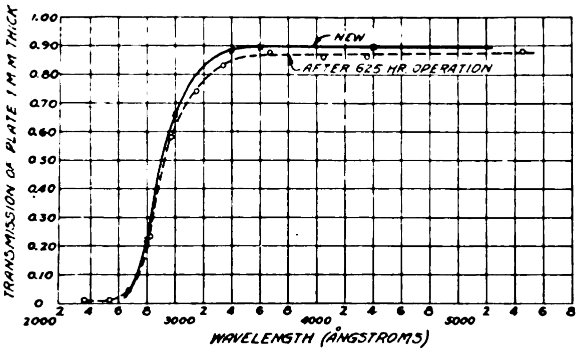


Fig. 10. Transmission Test. New and old glass from bulb of Type S-1 lamp

The bulb of special glass transmits very little energy (less than 0.04 per cent of total input) below 2800Å and, acting as a filter, eliminates in a large measure the shorter rays of the mercury arc which are most irritating to the eyes. Most people will probably find it unnecessary to use goggles provided the usual precaution of not looking directly at any intense source of light is observed and the recommended time and distance of exposure are followed. The transmission curve for a single bulb chosen as a sample is plotted in Fig. 10 for a wall thickness of 1 mm. The bulbs vary somewhat in thickness, but 1 mm. is close to the average. The transmission of a bulb after operating for 625 hours is 92 per cent of the initial value at 3000Å.

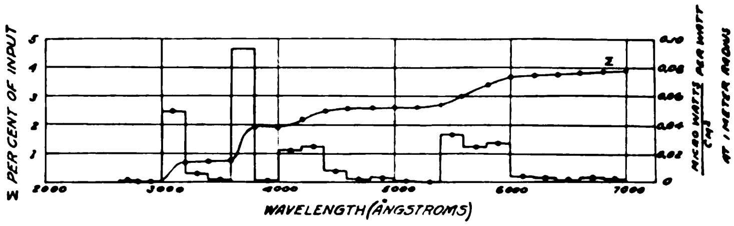


Fig. 11. Spectroradiometer Test of Type S-1 Lamp. Arc radiation only, 30 amp., 10.55 volts, 316.5 watts

(9). Spectrum Analysis

The tungsten electrodes of the arc operate at a temperature of about 3200 deg. K. against the average temperature of 2200 deg. K. of the filament. The electrodes, therefore, produce more light than the filament in spite of its large area, and the light from all tungsten parts amounts to 76 per cent against 24 per cent from the arc. The lamp, considered as a source of light, is therefore a tungsten lamp modified by the presence of the mercury arc spectrum, but in the therapeutic region around 3000Å the case is reversed. The tungsten energy here is only about two hundredths of one per cent, while the mercury radiation is eight-tenths of one per cent of the electrical input of the lamp. The therapeutic radiation is therefore almost exclusively due to the arc radiation.

In Fig. 11 the arc spectrum is analyzed in regions 200 Ångstroms wide, and the energy curve is plotted as a rectangular line. This curve reads on the right-hand edge of the web, where the spectral intensity is given in microwatts per square centimeter at a radius of one meter for a lamp input of one watt. For the lamp under consideration the energy should be multiplied by 316.5, the wattage of the lamp. For this particular lamp there was practically no energy found below 3000Å, but on other samples of presumably identical lamps there is usually found measurable amounts of energy at 2800Å, due largely to variations in the thickness of the glass. Fig. 12 shows the analysis of the entire radiation from a Type S-1 lamp, and here there is considerable energy above 6000Å, due almost entirely to the tungsten parts, and a small amount of energy below 3000Å that was not observed during the analysis of the lamp of Fig. 11. There are several points in the arc spectrum, notably at 3500, 3900, and 5300Å, where there is relatively little energy within the 200Å band of the analysis, and in Fig. 12 a smooth curve was drawn through these points. The area below this curve is due to tungsten radiation, while the area above it up to the rectangular curve is mercury arc radiation. Thus at 5500Å the tungsten furnishes $0.040 \frac{\mu W}{cm^2}$ at one meter while the arc furnishes $0.075 - 0.040 = 0.035 \frac{\mu W}{cm^2}$ at the same distance for each watt of lamp input.

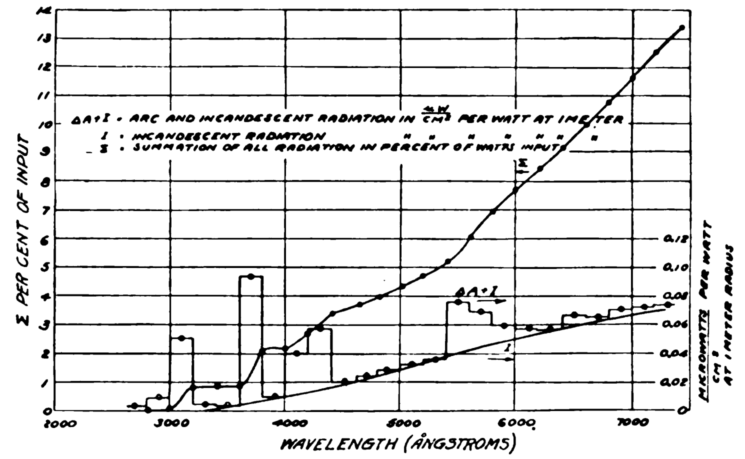


Fig. 12. Spectroradiometric Test of Type S-1 Lamp, 30 Amp. 10.9 Volts, 316 Watts

TABLE II

SPECTRAL DISTRIBUTIONS IN PERCENTAGE AND MICROWATTS

WAVELENGTH		Sun (Max.) Per cent	Sea Level $\frac{\mu W}{cm^2}$	SUNLAMP—BARE LAMP ONLY	
From	To			Per cent	$\frac{\mu W}{cm^2}$ at 1 meter
0	3200	0.11	120	0.8	20
3200	4000	3.00	3,180	1.4	35
4000	7000	38.89	41,200	9.4	237
7000	Inf.	58.00	61,500	88.4	2233
Total..........		100.00	106,000	100.0	2525

On the left of Figs. 11 and 12 the energy in the spectrum is summed up and expressed as a percentage of the total electrical lamp input. Some of the significant figures are 0.8 per cent below 3200Å, 3.8 per cent from the arc below 7000Å, and 11.6 per cent from arc and tungsten below 7000Å. In Table II further data are given.

The ratio of energies from the sun and the Sunlamp in the 0–3200Å region is here given as 120 to 20 or six to one. As has already been noted, the effective erythema energy is only two to one, and this illustrates one danger of making comparisons on the basis of unreduced energy values. The explanation here is that the radiation from the artificial source is in better wavelength agreement with the erythema curve.

In order to compare the energy from the Sunlamp complete (with reflector) with sunlight it is most convenient to make the comparison on the basis of energy received on a square centimeter of surface one meter from the Sunlamp.

Table II shows us in general terms how much erythema radiation is present in the S-1 lamp spectrum, but if more precise data are desired it is necessary to examine the spectrum between 2800 and 3200Å more in detail, as is done in Fig. 13. Here five main lines, or groups of lines are shown in their relative irradiation strengths along with the erythema curve. The product of microwatts and erythema factors gives erythema irradiation units (E') for each line. The strengths of the lines, as energy, are indicated by the circles, while the erythema units (E') are given by the cross line under each circle. The total of erythema irradiation units, including a line at 3150Å, not shown, is 4.79 E' from the bare lamp. As will be shown more in detail later, the reflector used with the lamp about doubles this value in the area covered by the reflected beam, and the erythema irradiation strength at one meter is about 9 E' as compared with a maximum possible 10.6 E' from the sun, and a yearly average of only 4.80 E' from the noon sun, assuming a cloudless sky every day of the year.

The Type S-1 lamp when used with its reflector is thus stronger at a radius of one meter than the average noon sun for nine months of the year, as illustrated in Fig. 7, and if we include cloudy and rainy days in the computation the artificial radiator is definitely superior as a year-round source of erythema rays.

(10). Angular Distribution of Light and Ultra-violet Energy

The reflector of the Sunlamp unit is oxidized aluminum, which is a fair reflector of both light and ultra-violet. In Fig. 14 Curve A shows the downward distribution of light from the bare lamp. Curve B is the distribution of light from the lamp with its reflector, but without the protective wire screen that fits over the opening of the reflector. With the screen in place the distribution is as in Curve C.

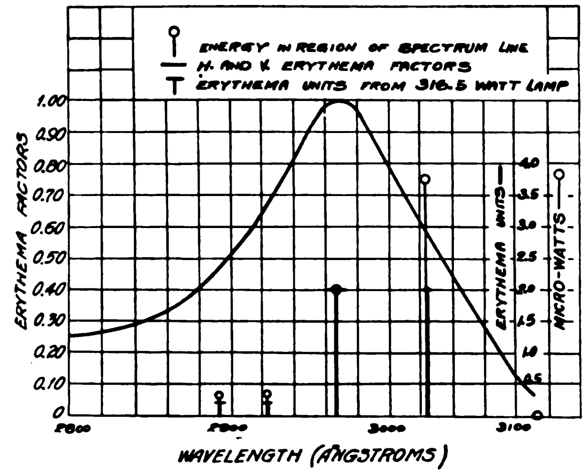


Fig. 13. Spectrum (Arc and Incandescent) Analysis of G-E Type S-1 Lamp, 30 Amp., 10.55 Volts, 316.5 Watts, Lamp Only

The 2800–3200Å radiation is illustrated in Fig. 15 in which Curve A gives the bare lamp radiation, B is lamp plus reflector, and C is from the unit complete with screen. It will be observed that Curve C crosses B and with the screen in place the center of the beam is more intense than without it. This apparent contradiction is explainable by the changed ventilation conditions when the screen is added. By slightly checking the ventilation and by heating the ventilating air that passes through it, the screen raises the temperature of the lamp, and this rise causes the mercury vapor to increase in pressure. This in turn makes the mercury vapor a better radiator, but it has but little effect upon the radiation from the tungsten. The increase in ultra-violet radiation more than makes up for the loss by absorption by the screen and the ultra-violet increases except around the edges of the beam where the direction of incidence on the wire mesh reduces the transmission to a low value.

The width of the beam from the unit is over 100 deg., so that at a radius of one meter a circle 2.2 meters, or over seven feet in diameter, is fully radiated. This distribution makes it possible to expose practically the whole body of an adult at one time, or to provide an area in which one or more children can move about and play while they are being irradiated.

The unit when used as a combined irradiator and reading lamp provides a level of illumination that is higher than is customary, some 130 ft-cd. at one meter, but this is not an excessive illumination if care is taken to hold the book or paper so as to avoid glare spots. There is one possible objection to using this unit for reading purposes, and that is that the reader is apt to remain too long in one position and over-expose one portion of his body instead of changing position frequently and thus securing a mild irradiation over an extended area.

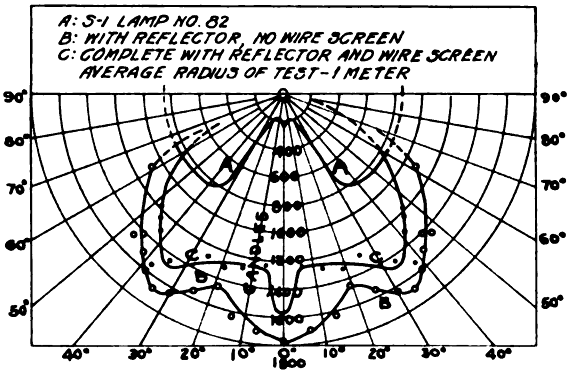


Fig. 14. Photometric Test Preliminary of G-E Sunlamp, 115 Volts

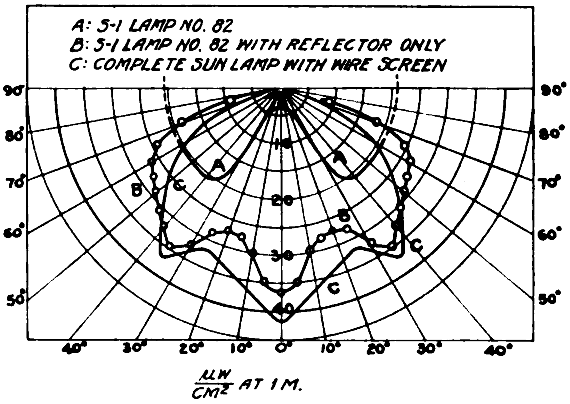


Fig. 15. Radiometric Test (Preliminary) G-E Sunlamp, 115 Volts. Microwatts, ultra-violet energy, 2800-3200Å, falling on one cm² at one meter radius

(11). Input-radiation Characteristics

The relation between light and current input is illustrated by the three curves in Fig. 16. The amount of light from the arc is increased only 16 per cent for an increase of 25 per cent in current, or from 24 amp. up to 30 amp. This shows that the arc, as a light source, and as distinguished from an ultra-violet source, is near its maximum efficiency and that little is to be gained by further increase in current. In considering the total light output it is well to distinguish between the filament, which operates at arc voltage, and the electrodes which are heated by their relation to the arc. At increasing current the arc voltage drops, and the filament being in shunt with the arc takes less current and should give less light. On the other hand, the upper parts of the filament are heated more by the expanding arc at higher currents and the light from these filament areas is increased. The net change in filament light output is probably a slight increase as the current changes from 24 to 30 amp.

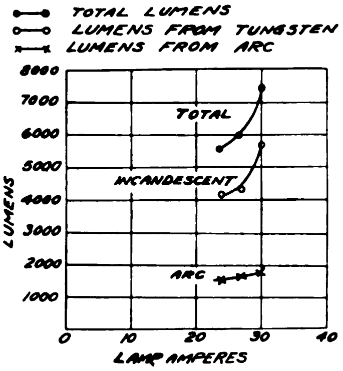


Fig. 16. Ampere-lumen Characteristic of Type S-1 Lamp, Without Reflector

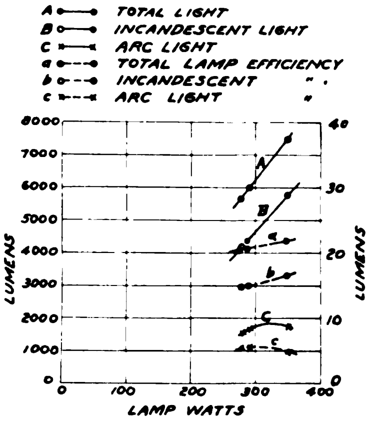


Fig. 17. Watt-lumen Characteristic of Type S-1 Lamp, without Reflector

The electrodes, and their supports, operate at increased temperatures as the current increases, largely because the arc stream expands and encloses more of the electrodes and supports, and the increase in light from the incandescent parts is almost wholly caused in this way.

(12). Life and Maintenance of Ultra-violet and Variation of Ultra-violet with Voltage

Before considering the maintenance of ultra-violet radiation in the Type S-1 lamp it will be of interest to call attention to the variation of ultra-violet with change of line voltage applied to the transformer. Table III contains data on the electrical characteristics as well as a measure of the variation of the ultra-violet energy from the Type S-1 lamp as the voltage on the primary of the transformer is increased from 100 volts to 125 volts. The curve in

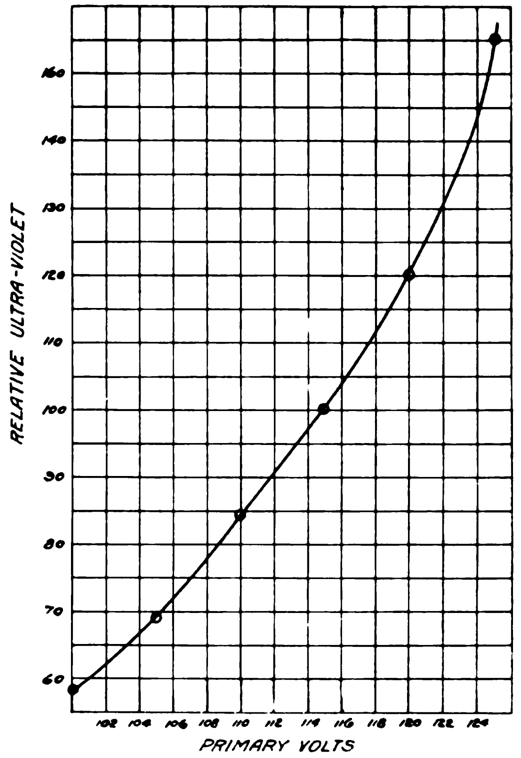


Fig. 18. Relative Ultra-violet vs. Primary Volts, Type S-1 Lamp

TABLE III

VARIATION OF ULTRA-VIOLET BELOW 3200Å WITH CHANGE OF PRIMARY VOLTS, TYPE S-1 LAMP

A vacuum quartz sodium photoelectric tube and window glass filter used in measuring ultra-violet. Eighteen inches between electrodes and cell. Lamp used with no reflector. Ultra-violet at 115 volts = 100 per cent.

PRIMARY			SECONDARY			PHOTOTUBE READING			
V	A	Watts	V	A	V-A. or Watts	No Screen	Window Glass	Rel. U.V.*	Per Cent U.V.
100	8.4	369	11.1	26.1	290	2.75	0.75	2.00	58.5
105	8.75	387	10.75	27.7	298	3.22	0.87	2.35	69
110	9.3	415	10.6	29.6	314	3.9	1.02	2.88	84.5
115	9.8	440	10.58	31.3	331	4.6	1.19	3.41	100
120	10.4	472	10.55	33.1	349	5.5	1.4	4.1	120
125	10.9	502	10.6	34.5	366	6.8	1.7	5.1	150

* Correction for the absorption and reflection of the window glass has not been applied. A correction may reduce these figures 3 or 4 per cent but other factors such as ventilation and bulb darkening may cause greater changes.

Fig. 18 shows graphically the relation between the relative ultra-violet energy radiated and the primary voltage. If this curve is plotted on a logarithmic scale one obtains approximately a straight line over the range covered and this result may be expressed in the form

$$\text{Ultra-violet} = kV^a$$

in which a has a value of 4.1.

Fig. 19 shows a similar relation for ultra-violet output with variation of the watts in the lamp and may be expressed as

$$\text{Ultra-violet} = kW^b$$

In this instance b has a value of 3.6.

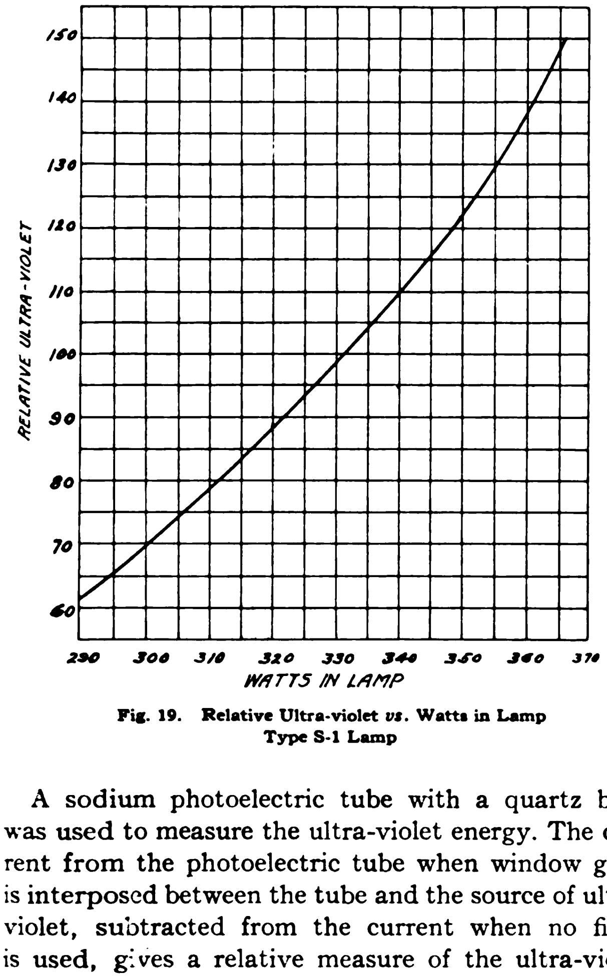


Fig. 19. Relative Ultra-violet *vs.* Watts in Lamp Type S-1 Lamp

A sodium photoelectric tube with a quartz bulb was used to measure the ultra-violet energy. The current from the photoelectric tube when window glass is interposed between the tube and the source of ultra-violet, subtracted from the current when no filter is used, gives a relative measure of the ultra-violet energy radiated in the spectral region bounded by window glass and the special glass of the bulb. The photoelectric tube used for these measurements has a maximum sensitivity close to 3100Å and the curve for its relative sensitivity at different wavelengths is shown in Fig. 20. The figure also contains the transmission curve for the window-glass filter and shows practically no energy at 3130Å. This method of measuring the ultra-violet energy is not capable of detecting changes in individual lines, but it does give a relative measure of the energy for the region considered as a unit. The region lying between the transmission curves for window glass and the special glass also corresponds closely to the wavelengths which are effective in the production of erythema.

Three groups of lamps were measured initially and at 50 hours life for maintenance of ultra-violet by means of the quartz photoelectric tube. Table IV shows that the ultra-violet energy from the lamps at 50 hours is about 120 per cent of the initial value. This seems somewhat surprising especially since the bulbs are often quite dark in appearance. A further examination of the figures shows, however, that the wattage in the lamp has increased from 332 to 360 watts. This increase in wattage may be caused by several factors, but probably the higher operating temperature of the lamp due to the blackening is most important. At the higher temperature of the bulb and the resulting higher mercury pressure the voltage across the arc increases and the special transformer supplies an increased wattage at this higher voltage. In order to obtain a similar effect but with no blackening, a clear lamp with full circulation of air was allowed to reach a steady temperature and

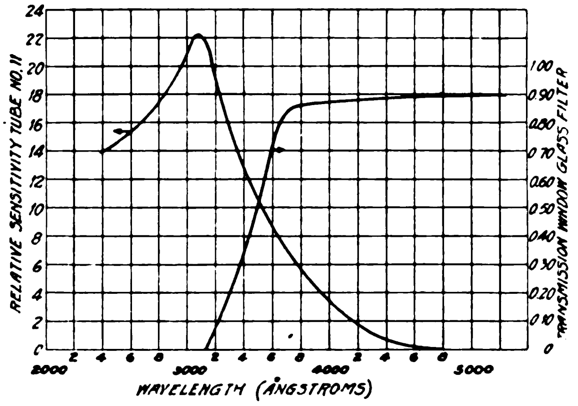


Fig. 20. Spectral Sensitivity of Sodium Photoelectric Tube and Transmission of Window-glass Filter

TABLE IV

ULTRA-VIOLET MAINTENANCE, TYPE S-1 LAMP

Relative Measure Below 3200Å. 115 Volts on Primary of Transformer

Lot	INITIAL			50 HOURS					
	V	A	W	V	A	W	Ave. Per cent U.V.	Per cent U.V. Max.	Per cent U.V. Min.
5 (6 lamps)	11.4	31.1	354	12.2	30.5	373	114	133	100
7 "	10.0	31.9	319	11.7	30.8	360	129	155	95
9 "	10.4	31.3	326	11.1	31.1	345	116	129	88
Ave.	10.6	31.4	332	11.7	30.8	360	119		

the wattage and ultra-violet measured. Ventilation was then restricted by placing a metal cylinder around the lamp and the ultra-violet was again measured through a hole about 1 inch by 2 inches in the side of the cylinder. Owing to the higher operating temperature of the bulb, the wattage increased 10 per cent and the ultra-violet 50 per cent. Thus it is indicated that the blackening reduces the emitted ultra-violet about 20 per cent, which is easily understood considering the appearance of the lamp. The net result, however, is an increase of about 20 per cent in the ultra-violet output after operating for 50 hours.

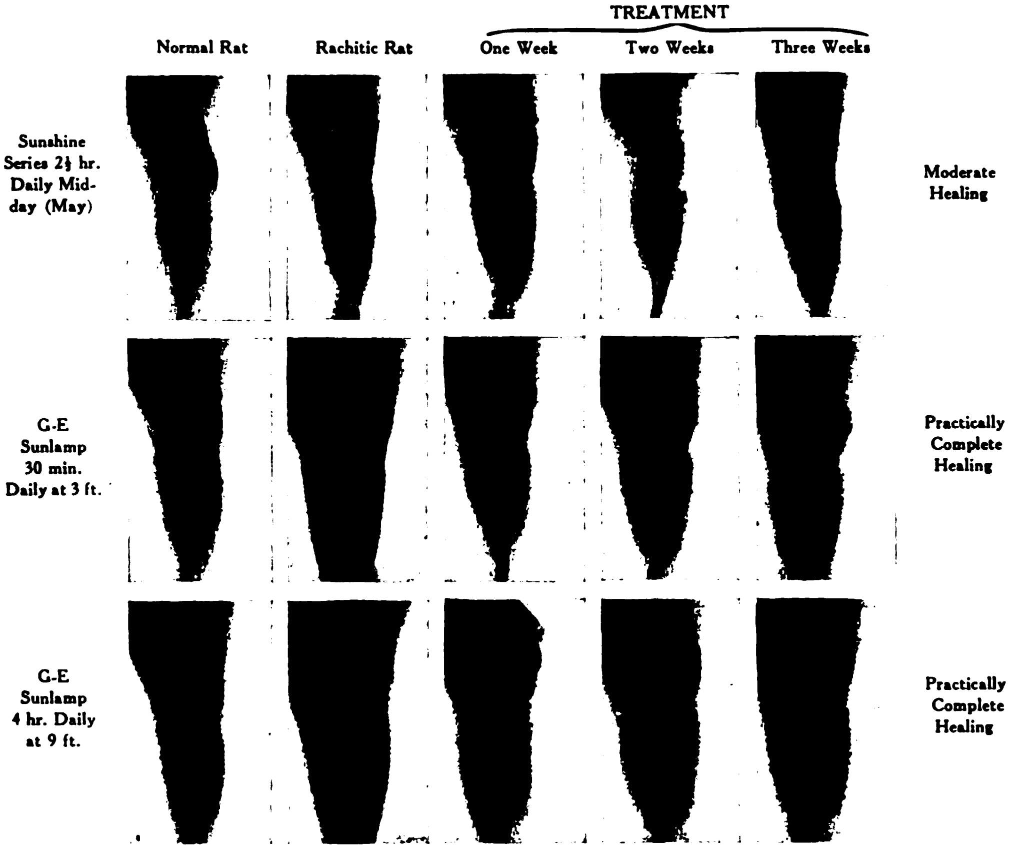

TREATMENT
Normal Rat
Rachitic Rat
One Week
Two Weeks
Three Weeks
Sunshine Series 2½ hr. Daily Mid-day (May)
Moderate Healing
G-E Sunlamp 30 min. Daily at 3 ft.
Practically Complete Healing
G-E Sunlamp 4 hr. Daily at 9 ft.
Practically Complete Healing

Fig. 21. X-ray Photographs Showing Comparative Effects of G-E Sunlamp and May Sunshine for Treatment of Rickets

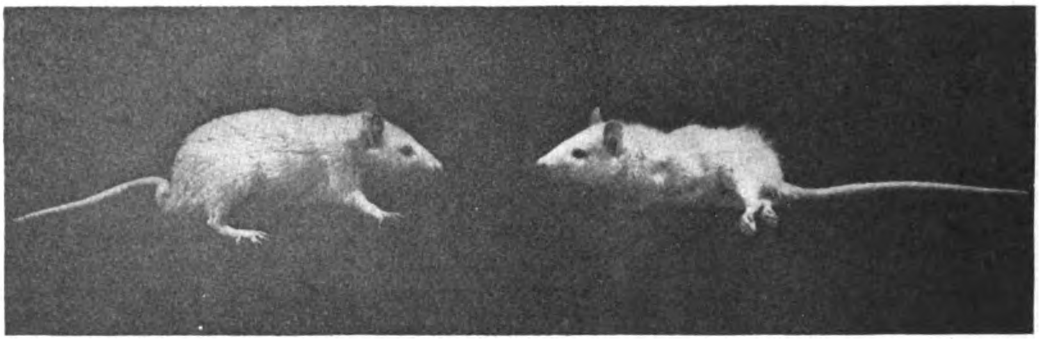


Fig. 22. Both of these rats were fed for seven weeks on a rachitic diet. After the fourth week, the rat on the left was treated daily with the Sunlamp for 30 min. at 3 ft. The other rat received no ultra-violet treatment and was unable to walk at the end of this period

A few measurements at 150 hours indicate that the ultra-violet radiation in a horizontal direction is about 115 per cent of the initial and in general it has not fallen below 100 per cent throughout the life of the lamps except in case of lamps having uncommonly long life.

It is difficult to obtain an accurate estimate of the life which may be expected from the Type S-1 lamps in actual service because of the variable conditions under which they may be used. In addition to variations in line voltage, other factors such as position of lamp during burning, frequency of starting, mechanical shock, and vibration may all influence the life of the lamps and cause erratic performance. However, the results of laboratory tests on ultra-violet maintenance indicate that, except for an occasional early failure, the Type S-1 lamps should provide several months' service for average home use.

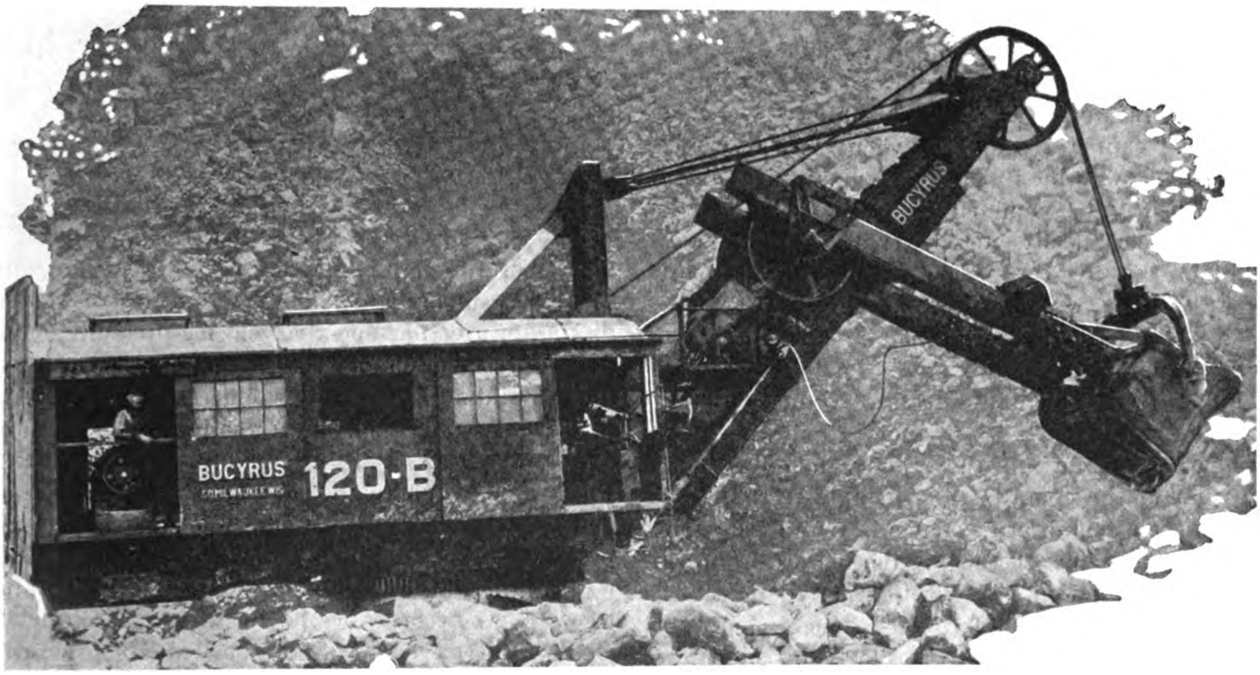
(13). The G-E Sunlamp and Rickets

In foregoing sections of this article the Sunlamp is compared with sunlight by means of physical measurements of both the lamp and the sun. In order to supplement these physical measurements with data having a biological significance experiments were conducted by Dr. A. Knudson of the Albany Medical College comparing the therapeutic effects of natural sunlight and the G-E Sunlamp on rachitic rats. Although experiments are still in progress to determine the minimum exposure necessary to prevent and cure rickets, we are permitted through the kindness of Dr. Knudson to present x-ray pictures (Fig. 21) showing the cure of rickets in rats by the G-E Sunlamp.

The pictures represent three series of experiments: the first, the effect of sunshine; and the last two, the effect of the G-E Sunlamp in the healing of rickets. The first column in all series shows the bones of the leg of a normal rat, and the second column the bones of rachitic rats of the same age. In producing a severe degree of rickets, rats four weeks of age were put on Steenbock's rachitic diet No. 2965 for three weeks and were permitted no exposure to outdoor sunlight or other source of ultra-violet radiation. The last three columns show the condition of the rats after the first, second and third week of treatment with sunshine or the G-E Sunlamp. It will be observed in the last picture of the sunshine series that 2½ hours daily exposure to May sunshine caused moderate but not complete healing of the rickets. Compensation was made for cloudy days by increased time of exposure on the next clear day. The last pictures in both of the Sunlamp series show practically complete cure of the rachitic condition and indicate that time of exposure may be calculated approximately by the reciprocity relation (Time×Intensity = Constant), in which the intensity is computed by the inverse square law of radiation. The second series indicates that an exposure of 30 minutes to the G-E Sunlamp at a distance of three feet is more effective in the treatment of rickets in rats than 2½ hours of May sunshine.

Further experiments on rats to determine minimum exposure both for prophylactic and therapeutic doses are in progress and will be published in more detail by Dr. Knudson.

An Electric Revolving Type of Quarry Shovel at Work



Heat Transfer in Jacket-cooled Centrifugal Compressors*

Cooling in Compressors—Heat Transfer—Volumetric Load—Cooling Water—Speed and Density

By M. G. ROBINSON
Turbine Engineering Department, Lynn Works
General Electric Company

AIR and gas compressors designed for any but very moderate pressures are, as a rule, water cooled in order to reduce the theoretical work required by the compression process. The pressure-volume diagram in Fig. 1 shows an example of such a saving. Area "A" is the actual saving due to cooling; area "B" is the additional saving possible with cooling sufficient for isothermal compression.

The saving effected becomes greater the higher the discharge pressure. In the case of reciprocating compressors—the usual type for very high pressures, where cooling is most essential from considerations of economy—the cooling is accomplished mostly in external coolers. In the case of centrifugal compressors, a high discharge pressure implies multistage construction, the pressure capacity of each stage being limited by the allowable peripheral speed of the impellers. The use of several stages makes available a large surface over which the fluid sweeps at high velocity. Conditions are thus quite favorable for a good rate of heat transfer in internal or jacket coolers. Of course, cases arise when external coolers are used in addition to jacket cooling. The present discussion will be confined to jacket cooling only, and more specifically to the type of compressors manufactured by the General Electric Company. The test data available at this time are all based on air. The discussion will, therefore, be limited to operation with air.

The ability to estimate effects of water cooling is of value from two points of view. First, from that of the designer as affecting the economy; second, from that of the operator, *i.e.*, in industrial applications where a definite knowledge is required of temperature conditions of the air discharge, or of the quantity of heat removed. To forecast the effects of water cooling under different conditions of operation, one must have knowledge of the laws of heat transfer applying to this particular case. It is the purpose of this article to establish some simple relations among the factors affecting the flow of heat from the hot air to the cooling water.

The Cooling Process

The construction used by the General Electric Company is clearly shown by Figs. 2 and 3. The cooling water is usually introduced at the bottom and flows upward through the jacket space in a somewhat tortuous, irregular manner. The air is discharged by the first impeller into the narrow passage *AB*, Fig. 2, which is known as the diffuser. The function of the latter is to convert the kinetic energy of the high velocity jet discharged by the impeller into pressure energy. This is accomplished by so shaping the passage that the stream in its flow outward is gradually slowed down, with a consequent rise in pressure and temperature. At the end of the diffuser passage the velocity-pressure conversion process is complete. The fluid now crosses over into the interstage passage connecting the first stage with the second, and flows radially inward as shown by arrows *CD*, Fig. 2, to the inlet of the second-stage wheel, and so on to the discharge of the last stage. Thus, although there is a continual increase in temperature of the air due to the rising pressure, there is also the continual tendency of the temperature to decrease because of the heat carried off by the cooling water which washes the walls of practically all the passages through which the air is flowing.

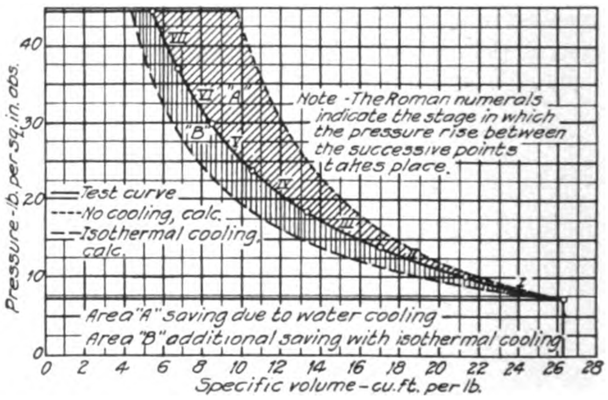


Fig. 1. Indicator Diagram of a Seven-stage Centrifugal Compressor, Illustrating the Effect of Water Cooling

An idea as to the actual state of affairs existing may be secured from a study of Fig. 4 which represents test temperature-pressure observations made on a seven-stage compressor; operated first as an exhauster, with the air pressure at the inlet reduced to about 7.5 lb. per sq. in. absolute; and then as a compressor, *i.e.*, with full atmospheric pressure at inlet, the discharge pressure being about 45 lb. per sq. in. abs.

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* The present article is based partially on material in the author's M. Sc. thesis (Mass. Institute of Technology, 1927).

in both cases. It will be noted that the temperature at first rises quite rapidly. Soon, however, as the temperature difference between the air and water has become high and as the air density has increased, the cooling becomes quite effective, sufficiently so that in the fifth and subsequent stages the compression is isothermal or better.

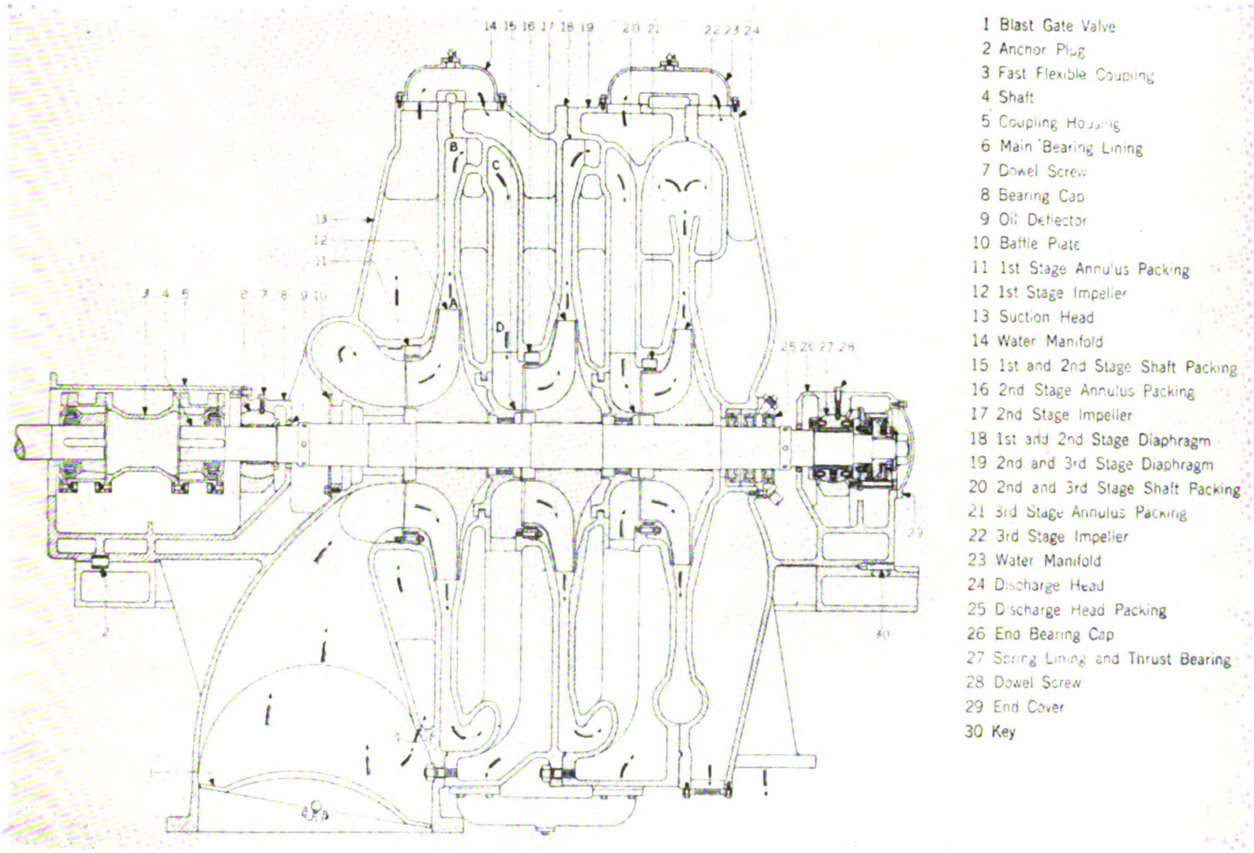
14 15 16 17 18 19
20 21
22 23 24
13
12
11
3 4 5
6 7 8 9 10
A
B
C
D
25 26 27 28
29
2
30
1 Blast Gate Valve
2 Anchor Plug
3 Fast Flexible Coupling
4 Shaft
5 Coupling Housing
6 Main Bearing Lining
7 Dowel Screw
8 Bearing Cap
9 Oil Deflector
10 Baffle Plate
11 1st Stage Annulus Packing
12 1st Stage Impeller
13 Suction Head
14 Water Manifold
15 1st and 2nd Stage Shaft Packing
16 2nd Stage Annulus Packing
17 2nd Stage Impeller
18 1st and 2nd Stage Diaphragm
19 2nd and 3rd Stage Diaphragm
20 2nd and 3rd Stage Shaft Packing
21 3rd Stage Annulus Packing
22 3rd Stage Impeller
23 Water Manifold
24 Discharge Head
25 Discharge Head Packing
26 End Bearing Cap
27 Spring Lining and Thrust Bearing
28 Dowel Screw
29 End Cover
30 Key

Fig. 2. Sectional Assembly of a Water-cooled Compressor

Factors Influencing the Rate of Heat Transfer

The preceding discussion, and a study of the flow conditions through the machine, make apparent the complexity of the problem confronting one who would attempt to establish the exact temperature conditions at all points in the machine by a step-by-step calculation, taking into due account all of the factors involved in the heat transfer. The major factors are: the extent of the cooling surface; the relative effectiveness of each element of cooling surface as determined by the shape of the passage; the temperature difference, air to water, properly interpreted in the formulas in the light of the particular flow conditions existing; the velocity and density of the air; the amount of cooling water and its rate of circulation through the jacket spaces. A search through the extensive literature on the subject of heat flow brings no solution. The data are almost exclusively confined to boiler and condenser tubes where the character of flow is fairly definite, and the velocities are rather moderate when compared with the case under consideration where velocities of several hundred feet per second are dealt with. There is practically no information as to the effect of shape of passage. There is but little definiteness when it comes to absolute values of the coefficients.

Still, some general conclusions may be drawn, summed up as follows: The total resistance to the heat flow is made up of the resistance from the air to the metal, largely through the air film; the resistance through the metal; and the resistance from the metal to the cooling water, largely through the water film. Of these, by far the most important one, is the resistance from the air to the metal; that through the metal is practically negligible.

Many equations have been proposed to cover the case of heat flow from the air to a metal surface. Of these, we may cite Nüsselt's,(1) based on elaborate tests on a tube 0.866 in. dia.

$$h = 0.00114 \left(\frac{w}{a}\right)^{0.786}$$

where

h = heat transfer coefficient, B.t.u. per sec. per sq. ft. per deg. F. temp. difference
w = air flow, lb. per sec.
a = area of passage, sq. ft.

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(1) "Der Wärmeübergang in Rohrleitungen," *Zeitsschrift des Vereines deutscher Ingenieure*, 23rd and 30th October, 1909.

One could use Nüsselt's data to approximate the heat carried off by the cooling water by a step-by-step calculation, taking account of the continual pressure, temperature, and velocity variation from the inlet of the machine to the discharge, and either disregarding the shape factor and the influence of the water velocity, or else making some allowance based on tube tests judged most applicable, but in any case probably quite arbitrary. Even this would prove a laborious process, in many cases entirely unjustifiable, when one considers the approximate nature of the data available. The advantage is thus obvious of having some direct means of dealing with the *complete machine*, *i.e.*, of having a sort of an overall heat transfer coefficient and establishing its laws of variation with changing conditions of operation. An attempt will be made to do this on the basis of certain simplifying assumptions, checking the ultimate validity of the scheme against test evidence. As far as the writer is aware, there is no similar treatment of the matter available in the literature.

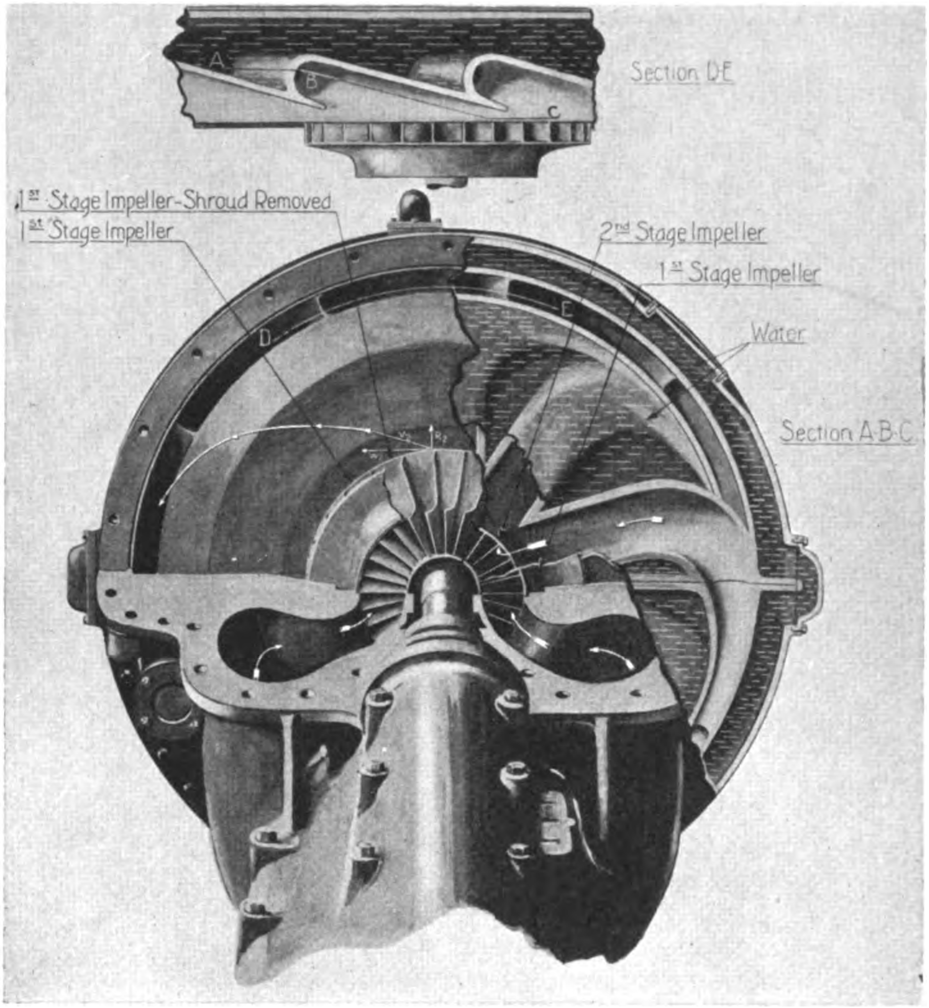

Fig. 3. Sectional View of a Centrifugal Compressor

It will be assumed that the major factors governing the heat flow are: the temperature difference, air to water; the air velocity and density; and the quantity and velocity of cooling water On account of the variable character of the flow of both the air and the water, no attempt will be made to deduce specific theoretical rules for using the temperature difference, air to water, as is done in case of both parallel and counter-flow heat exchangers. It will be assumed that the net temperature difference will be that between the average air and the average water temperature. Since the velocity of the air at any point in the machine is a function of the speed of rotation and of the volumetric load, these last two variables will be used to replace the velocity variable in the general expression for the heat transfer coefficient.

Hence, the heat transfer coefficient of a *given machine* will be of the form

$$\frac{H}{\Delta t_m} = f\,(C, Q, N, \gamma, W)$$

where H = rate of heat transfer from the hot air to the cooling water, B.t.u. per hr.

Δt_m = average temperature difference, air to water, deg. F.

$\frac{H}{\Delta t_m}$ = heat transfer coefficient, B.t.u. per hr. per deg. F.

f = some function to be determined.

C = some physical constant depending on the extent of the cooling surface, shape of passage and the thermal properties of air.

Q = volumetric load, cu. ft. per min.

N = speed or rotation, r.p.m.

γ = air density, lb. per cu. ft.

W = quantity of cooling water, g.p.m.

Before attempting to establish the general relations, we will examine the influence of the individual factors.

Effect of Volumetric Load

It is quite common in the discussions on heat transfer to use the term "mass flow." This is the term $\frac{w}{a}$ in Nüsselt's equation, where the coefficient of heat transfer is made to depend almost directly (0.8 power) upon this factor.

Consider the case of a centrifugal compressor operating at a constant speed and constant cooling water amount. If the density at the inlet is kept constant, then an increase in load or volume means a direct increase in the weight of air going through the machine. Should we then under these conditions expect a proportional increase in the coefficient? Reference to a vast amount of test data collected proves that this is far from being the case.

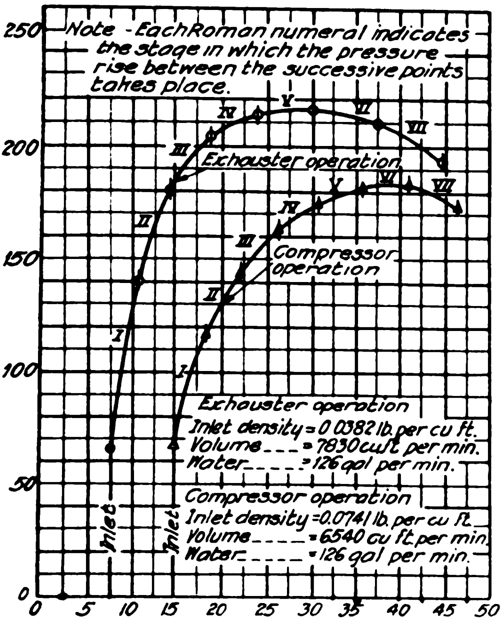

Fig. 4. Curves Showing Temperature Rise During Compression in a Seven-stage Compressor

Fig. 5 shows tests on four 3-stage machines with a large variation in capacity. For a range of load from 60 per cent to 150 per cent rated load, the coefficient increases only some 15 to 25 per cent. Similar data are available for a wide variation in size, number of stages, and speed of operation, all pointing to the same conclusion, *viz.*, that the variation of the coefficient is small, compared with the variations in load.

If we study the air flow through the machine we find a possible explanation. The type of impeller used by the General Electric Co. (usually radial blades) gives a fairly flat pressure characteristic, *i.e.*, at constant speed the pressure does not vary greatly with the volume. Neither does the temperature rise of the air change materially. Hence, the average density will remain sensibly constant. Now consider the velocity effect. The highest air velocity is in the diffuser passage AB. The cooling surfaces are also very large in this portion, so it is easy to imagine that the rate of heat transfer may be determined largely by the effectiveness of this portion of the machine. In the diffuser, the path of the air is a spiral, the angle of which varies with the load. At a constant speed of rotation, the absolute velocity at any point will change as the hypothenuse of a right triangle, with one side (the tangential component) constant and the other side (the radial or flow component) increasing in proportion to the volume. The absolute velocity will therefore be increased but slightly for a large increase in load.

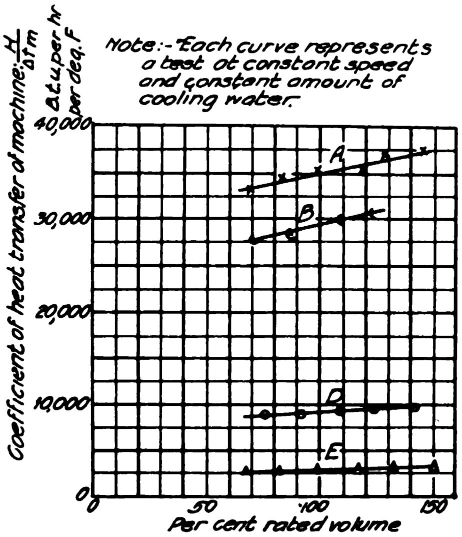

Fig. 5. Effect of Varying Compressor Load on the Coefficient of Heat Transfer in Three-stage Compressors of Various Capacities

A: Curve for compressor at 51,300 cu. ft. per min. at test speed
B: Curve for compressor at 47,150 cu. ft. per min. at test speed
D: Curve for compressor at 8,960 cu. ft. per min. at test speed
E: Curve for compressor at 3,440 cu. ft. per min. at test speed

Effect of Cooling Water Quantity

The results of varying the amount of cooling water are illustrated by Fig. 6 which reports a test with all other conditions kept constant.

In a general way, as the amount of cooling water is increased, the temperature rise of both the air and the water decreases; the total heat absorbed by the cooling water and the coefficient of heat transfer both increase. However, the decrease or increase of these factors is not even approximately proportional to the water velocity.

Tests similar to the one referred to may be used to evaluate the effect of water velocity on the resistance to the heat flow and hence on the coefficient of heat transfer.

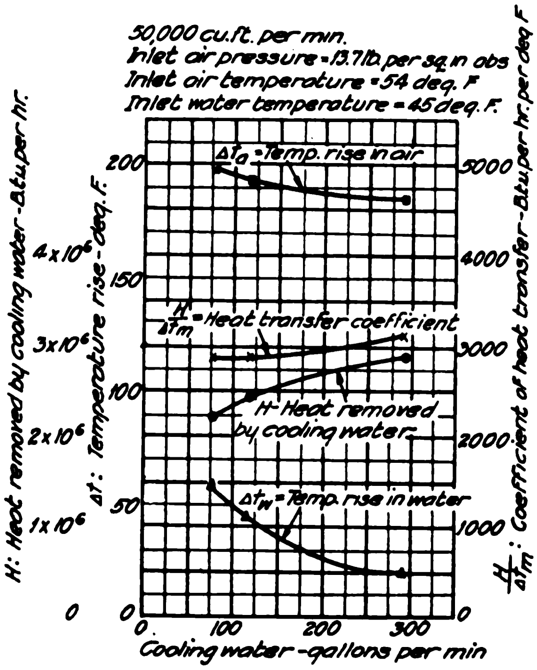

Fig. 6. Results from Tests on a Three-stage Compressor with Varying Amounts of Cooling Water

We introduce the following quantities in addition to those defined above:

R = the total resistance to heat flow from the hot air to the cooling water.
R_a = the resistance on the air side.
R_w = the resistance on the water side.
S = the extent of cooling surface.

$$X = \frac{W_1}{W}$$

$$r = \frac{H_1}{\Delta t_{m1}} \div \frac{H}{\Delta t_m}$$

Subscript 1 refers to operation with an amount of cooling water other than the normal.

Quantities without any numerical subscript refer to operation with normal amount of cooling water.

The heat flow, H, may be expressed by the relation

$$H = \frac{S\Delta t_m}{R}, \text{ or } \frac{H}{\Delta t_m} = \frac{S}{R} = \frac{S}{R_a + R_w}$$

disregarding the resistance of the metal wall as relatively insignificant.

Comparing two conditions of operation for a given machine, one with a normal amount of cooling water, W, the other with an amount of cooling water, W_1, all other conditions, such as speed, air volume, and inlet density being the same, we may assume that the resistances on the air side will be equal, *i.e.*, $R_a = R_{a1}$. Hence

$$r = \frac{H_1}{\Delta t_{m1}} \div \frac{H}{\Delta t_m} = \frac{R_a + R_w}{R_a + R_{w1}}$$

It seems fairly well established in the literature that the coefficient on the water side will vary approximately with the 0.8 power of the water velocity. That is, in the given case, the resistance will vary approximately inversely with the 0.8 power of the amount of cooling water used, or

$$R_{w1} = R_w \left(\frac{1}{X}\right)^{0.8}$$

Making this substitution, the expression for r reduces to

$$r = \frac{X^{0.8}}{1 + (X^{0.8} - 1)\dfrac{R_a}{R}}$$

Three ratios of R_a/R were assumed, *viz.*, 0.75, 0.85, and 0.95, and values of r calculated over a range of values of X. The resulting curves were used to provide a basis of comparison for the test points of Fig. 7.

These test points seem to confirm the belief that the resistance to the heat flow is made up largely of the resistance to the flow from the air to the metal, it being in the neighborhood of 85 per cent to 95 per cent of the total for the case considered. The resistance on the water side is relatively low. Hence the change in the water velocity has but a small effect on the overall heat transfer coefficient. When the amount of cooling water in a given machine is changed the major effect is usually due to the resultant change in the net temperature difference, and not to the change in the transfer coefficient.

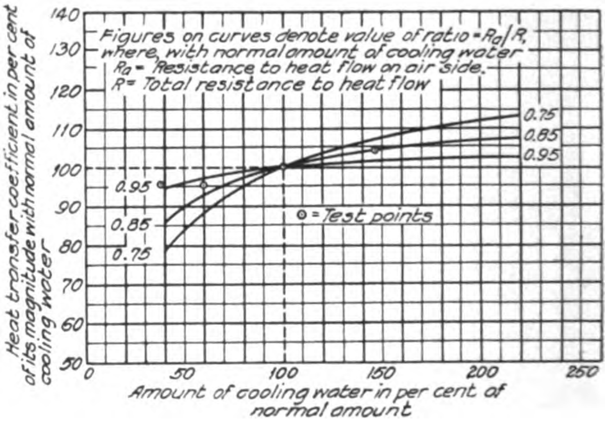

Fig. 7. Effect of Varying the Amount of Cooling Water on the Coefficient of Heat Transfer for a Three-stage Centrifugal Compressor, Illustrating the Relative Importance of Resistance on the Air Side

Effect of Speed and Density

The discussion in the preceding sections points to the fact that the scrubbing action of the high-velocity air exercises a strong influence upon the coefficient of heat transfer. It is logical to suppose that this action would be the more effective the greater the density, a hypothesis first proposed by Osborne Reynolds in 1874. In a given machine the velocity at any point is a function of the speed of rotation and of the volumetric load. By limiting the discussion to constant load operation we may work with the speed of rotation instead of the air velocity.

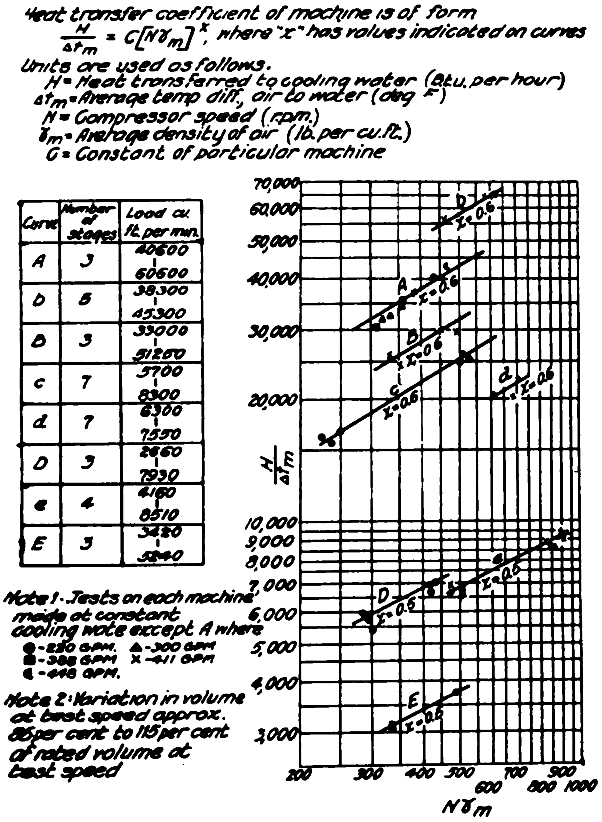

Fig. 8. Effect of Varying Compressor Speed and Density of Air on the Coefficient of Heat Transfer

The advantages are clear—no decision has to be made as to what is the representative velocity for the entire machine; and, furthermore, general conclusions may be formulated from an observed or test performance, thus obviating any reference to detailed drawings for the data necessary for velocity calculations.

Fig. 8 was prepared to investigate the effect of speed and density. Data were taken for a variety of operating conditions for eight machines of sizes varying from a booster of some 3000 cu. ft. per min. capacity to a blast furnace blower of some 70,000 cu. ft. per min. capacity. The operation of these machines covered inlet densities from about ⅛ normal atmospheric to full atmospheric, and pressure ratios up to 6 to 1. The points selected for each machine represent tests at approximately constant amount of cooling water, with the load limited to the range of 85 per cent to 115 per cent of the rated load at the test speed, in order to minimize the effects discussed in the two preceding sections.

Plotting the coefficient of heat transfer against the product of r.p.m. × average density, on logarithmic paper, results in a series of points for each machine through which a straight line can be drawn. The slopes of the lines indicate an exponent, $x = 0.5$ for the smaller machines and $x = 0.6$ for the larger machines.

The consistency of the data as plotted on the assumed basis seems to justify the use of the *average* temperature difference and of the *average* density throughout the machine. That is, for conditions of operation with an approximately constant amount of cooling water and at a volumetric load of an approximately constant percentage of the rated load, the coefficient of heat transfer is of the form

$$\frac{H}{\Delta t_m} = C\,(N\gamma_m)^x,$$

with the exponent x in the neighborhood of 0.5 to 0.6.

Conclusion

Briefly summed up, our study leads to the conclusion that, in machines of the type considered, the major factors determining the rate of heat transfer from the hot air to the cooling water are: the speed of rotation, the average density of the air, and the difference between the average air temperature and the average water temperature; changes in load or in cooling water amount are not so vital.

Whenever advisable, an allowance for change in load or cooling water amount may be made by reference to the discussion of these items. The simple relation,

$$H = C\,\Delta t_m \sqrt{N\gamma_m}$$

will approximate the heat flow to a degree satisfactory for the usual engineering estimates.

Acknowledgment is hereby gratefully made of the kind coöperation of co-workers during the progress of this study.

Features of 6.6-amp. *vs.* 20-amp. A-c. Series Circuits for Overhead Distribution in Street Lighting Systems

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IN an earlier article⁽¹⁾ the 20-amp. series circuit for street lighting was described, as well as other systems commonly employed for this purpose. This article, however, referred mostly to underground installations and very little reference, if any, was made to overhead distribution, although there was given a line loss analysis that might be referred to for making overhead analysis of overhead distribution of 6.6 and 20-amp. series circuits. In the present article there will be considered the following systems of distribution:

Overhead System (No. 6 wire)
- 6.6-amp. a-c. series system with 6.6/20-amp. auto transformers equipped with 6,000, 10,000, 15,000, and 20,000-lumen lamps.
- 6.6-amp. a-c. series system with 6.6/20-amp. individual-lamp transformers equipped with 6,000, 10,000, 15,000, and 25,000-lumen lamps.

20-amp. straight a-c. series system using No. 0 wire.
20-amp. straight a-c. series system using No. 2 wire.
20-amp. straight a-c. series system using No. 4 wire.
20-amp. straight a-c. series system using No. 6 wire.

In order to make a brief analysis of overhead a-c. series street lighting circuits covering the systems here tabulated, it will be found useful to refer to Fig. 1, which shows the relative comparison of the efficiency and power costs of using a series circuit with individual 6.6/20-amp. transformers and a straight 20-amp. series circuit. This comparison should apply in determining the advantages from this angle.

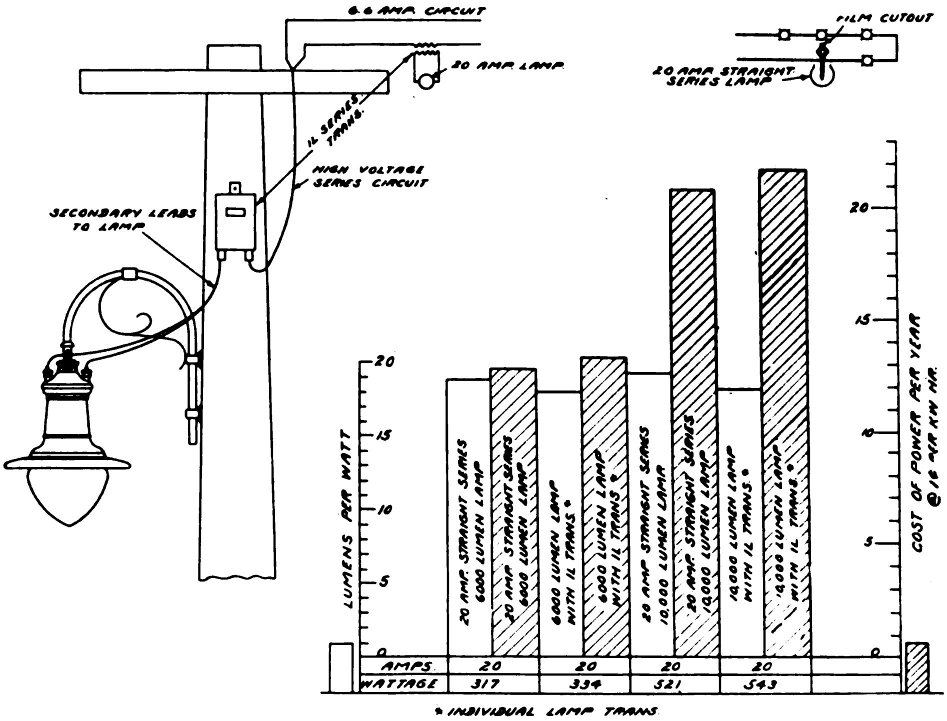

Fig. 1. Chart Showing Comparisons of a 6.6-amp. Series Circuit with Aerial Individual Lamp Transformers and a 20-amp. Straight Series Circuit

It will be observed by referring to Fig. 2, which gives the I^2R losses of No. 0, No. 2, No. 4, and No. 6 wire, that if a 20-amp. a-c. straight series system is considered for overhead distribution No. 0 wire might be considered in order to eliminate the excessive I^2R losses. This, however, increases the cost of copper to approximately 3½ times the cost of standard No. 6 wire, as shown in Fig. 3, which also gives the cost of individual lamp transformers for the various capacities.

From Table I it will be observed that the normal operating voltage is reduced approximately to one-third by using a 20-amp. straight series circuit, which will be less of a strain on the main overhead standard insulation in use, but this appears not to have a material advantage, particularly for overhead distribution,

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(1) "Features of 20-amp. A-c. Series Street Lighting Circuits," by Henry E. Butler. GENERAL ELECTRIC REVIEW, Vol. 31, October, 1928, p. 555.

as standard insulation is used, unless it is in a street that has considerable foliage; and this would help to eliminate surges in the line under these conditions. How much weight can be placed on this point of advantage is somewhat questionable, and local conditions will largely determine this factor. The 6.6-amp. straight series circuit of No. 6 conductor with individual lamp transformer for overhead systems of distribution to operate a 20-amp. lamp appears to be practically the standard practice, and from line analysis as shown in Fig. 2 together with the relative capacities for different size constant-current transformers in terms of the number of lamps operated as shown in Fig. 3, apparently indicates that it is a more efficient and economical system of distribution for overhead installation than that of a 20-amp. straight series system of distribution. The normal voltage operation (see Table I) of a 6.6-amp. constant-current straight series circuit operating an auto or individual-lamp transformer system is approximately three times that of a 20-amp. straight series system, but this should not be objectionable, especially for overhead distribution, as standard overhead insulation is used, regardless of voltage or capacity of the load. As previously mentioned, where there is considerable foliage (particularly in rainy weather) there might be experienced less surges in a line with a 20-amp. straight series system of distribution, as it has approximately one-third the normal operating voltage of a 6.6-amp. series circuit. How much consideration should be given this factor depends largely on local conditions.

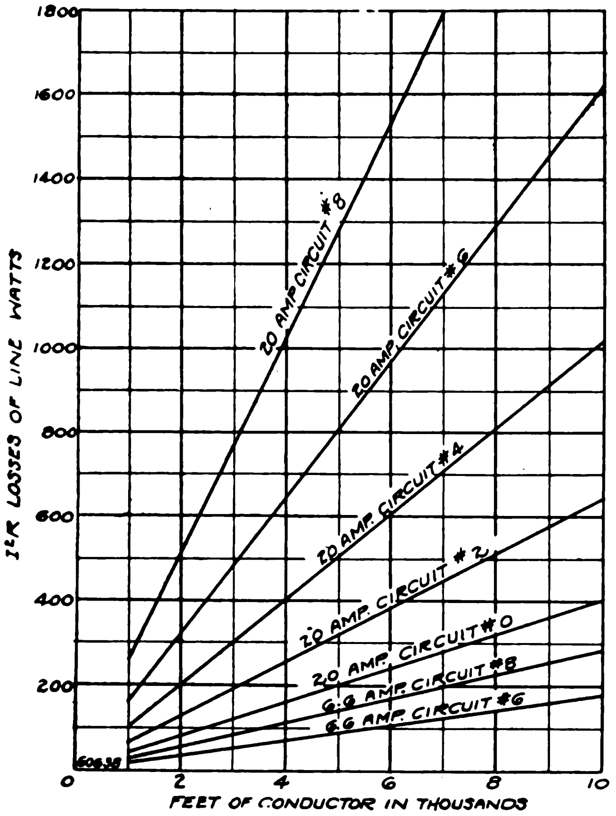


Fig. 2. Line Losses of 6.6 and 20-amp. A-c. Series Circuits

Whether the load is inductive or non-inductive is a factor that should also be given consideration, whether it is overhead or underground distribution of street lighting. Modern practice is to install the street lighting transformer equipments outdoors and operate lamps from the pole-type automatic transformer, thus eliminating the station floor space required for the station-type non-automatic transformer. Furthermore, the pole-type automatic constant-current transformer has additional advantages over the non-automatic type transformer which briefly are as follows:

(1). Admits of more flexible application
(2). Eliminates floor space at the station
(3). Makes automatic operation possible and does not require station operator
(4). Effects a saving in copper distribution.

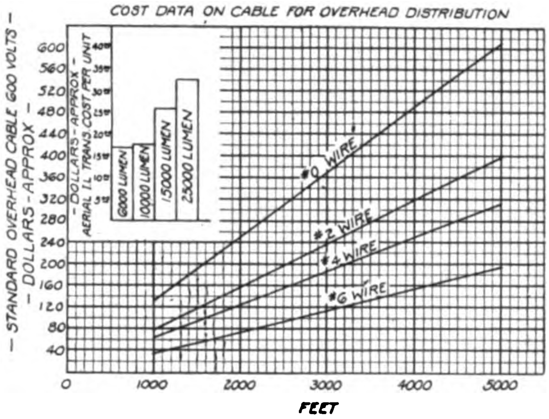
TABLE I

Capacity Kilowatts	POLE-TYPE CONSTANT-CURRENT TRANSFORMER, 6.6 AND 20-AMP. SECONDARY 60 CYCLES				Capacity Kilowatts	STATION-TYPE CONSTANT-CURRENT TRANSFORMER, 6.6 AND 20-AMP. SECONDARY 60 CYCLES			
	SECONDARY VOLTAGES					SECONDARY VOLTAGES			
	Full Load		Open Secondary			Full Load		Open Secondary	
	6.6 Amp.	20 Amp.	6.6 Amp.	20 Amp.		6.6 Amp.	20 Amp.	6.6 Amp.	20 Amp.
1	152	50	221	73	5	758	250	910	300
2	303	100	435	144	10	1515	500	1820	600
3	455	150	650	215	15	2275	750	2725	900
5	758	250	1075	355	20	3030	1000	3640	1200
7½	1136	375	1600	530	25	3790	1250	4550	1500
10	1515	500	2100	690	30	4550	1500	5455	1800
15	2270	750	3180	1050	35	5300	1750	6365	2100
20	3030	1000	4250	1400	40	6060	2000	7275	2400
25	3790	1250	5260	1740	50	7580	2500	9100	3000
30	4550	1500	6325	2090	60	9100	3000	10910	3600
					70	10600	3500	12750	4200

In order to make an analysis of non-inductive and inductive load for both types of constant-current transformers, reference should again be made to Fig. 3, which shows the number of lamps or street lighting units that can be placed on transformers of various capacities. It will be observed that for non-inductive load (*i.e.*, the straight series circuit) there is no difference in lamp capacities for non-automatic or automatic type of constant-current transformer, but for inductive load there is a difference in lamp capacities in favor of the station-type non-automatic constant-current transformer, due to a higher power-factor. However, the small differences in lamp capacities (inductive load) in favor of the station-type non-automatic constant-current transformer does not compensate for the advantages derived by the use of the pole-type automatic constant-current transformer. In practice it is found more economical to install the pole-type automatic transformer system, particularly for overhead distribution, and it is for this reason that most of the modern systems of distribution for street lighting are of this type. Therefore, the small number of lamp capacities (inductive load) in favor of the non-automatic type would appear not to favor that distribution as it is more modern and meets local conditions more economically. Therefore, attention is called to this phase of the problem if analysis of overhead distribution is to be made.

It will also be observed by referring to the non-inductive and inductive load analyses (Fig. 3) that the lamp capacities for the 20-amp. straight series system (non-inductive load) are higher but the difference might not appear to compensate for the advantages obtained by the use of the 6.6-amp. series lighting circuit with the individual lamp transformer.

POLE TYPE TRANSFORMER



AUTOMATIC STATION TRANSFORMER

FOR NON AUTOMATIC STATION TYPE TRANSFORMERS

#6 WIRE								
	LAMP EQUIPPED WITH (IL) TWO WINDING TRANSFORMER				LAMP EQUIPPED WITH AUTO TRANSFORMER			
NORMAL KW RATING	6000 LUMENS 20 AMP	10000 LUMENS 20 AMP	15000 LUMENS 20 AMP	25000 LUMENS 20 AMP	6000 LUMENS 20 AMP	10000 LUMENS 20 AMP	15000 LUMENS 20 AMP	25000 LUMENS 20 AMP
5	13	7	5	3	13	7	5	3
10	26	15	10	6	27	15	10	6
15	40	23	16	10	42	23	15	10
20	53	31	21	13	55	31	20	13
25	68	40	27	16	70	40	26	16
30	81	48	33	20	84	47	31	19
35	94	56	38	23	98	55	37	22
40	108	65	44	27	112	63	42	26
50	136	81	55	34	141	80	54	33
60	162	97	67	41	169	95	64	39
70	190	113	78	48	198	111	75	46

FOR AUTOMATIC STATION-POLE AND SUBWAY TYPE TRANSFORMERS

#6 WIRE								
	LAMP EQUIPPED WITH (IL) TWO WINDING TRANSFORMER				LAMP EQUIPPED WITH AUTO TRANSFORMER			
NORMAL KW RATING	6000 LUMENS 20 AMP	10000 LUMENS 20 AMP	15000 LUMENS 20 AMP	25000 LUMENS 20 AMP	6000 LUMENS 20 AMP	10000 LUMENS 20 AMP	15000 LUMENS 20 AMP	25000 LUMENS 20 AMP
3	6	4	3	2	7	4	2	2
5	12	7	5	3	12	7	4	3
7½	18	10	7	4	18	10	7	4
10	24	14	10	6	25	14	9	6
15	36	21	14	9	38	21	14	9
20	49	28	19	12	51	28	19	12
25	61	36	24	15	65	38	24	15
30	74	43	28	18	77	43	28	18
35	86	50	34	22	89	50	33	21
40	99	58	39	25	103	57	39	25
50	124	72	49	31	130	72	49	31
60	148	86	58	37	154	86	57	37
70	173	101	68	43	179	101	66	43

FOR AUTOMATIC AND NON AUTOMATIC STATION-POLE AND SUBWAY TYPE TRANSFORMERS

	#6 WIRE				#4 WIRE			
	20 AMPERE STRAIGHT SERIES CIRCUIT				20 AMPERE STRAIGHT SERIES CIRCUIT			
NORMAL KW RATING	6000 LUMENS ● 7.7%	10000 LUMENS ● 4.7%	15000 LUMENS ● 3.2%	25000 LUMENS ● 2%	6000 LUMENS ● 4.8%	10000 LUMENS ● 2.9%	15000 LUMENS ● 2%	25000 LUMENS ● 1.3%
• 3	9	5	4	2	9	5	4	2
• 5	15	9	6	4	15	9	6	4
• 7½	22	14	10	6	23	14	10	6
• 10	29	18	13	8	30	19	13	8
• 15	44	28	19	12	45	28	19	12
• 20	59	37	26	16	60	37	26	16
• 25	73	46	32	20	75	47	32	20
• 30	88	55	38	24	90	56	39	24
35	103	64	45	28	105	65	45	28
40	117	73	51	32	120	75	52	32
50	146	92	64	40	150	93	64	40
60	176	110	76	48	181	112	77	48
70	205	128	89	56	211	131	90	56

	#2 WIRE				#0 WIRE			
	20 AMPERE STRAIGHT SERIES CIRCUIT				20 AMPERE STRAIGHT SERIES CIRCUIT			
NORMAL KW RATING	6000 LUMENS ● 3%	10000 LUMENS ● 1.8%	15000 LUMENS ● 1.3%	25000 LUMENS ● 0.8%	6000 LUMENS ● 1.9%	10000 LUMENS ● 1.2%	15000 LUMENS ● 0.8%	25000 LUMENS ● 0.5%
• 3	9	5	4	2	9	5	4	2
• 5	15	9	6	4	15	9	6	4
• 7½	23	14	10	6	23	14	10	6
• 10	31	19	13	8	31	19	13	8
• 15	46	28	19	12	46	28	19	12
• 20	61	38	26	16	62	38	26	16
• 25	77	47	32	20	77	47	32	20
• 30	92	57	39	24	93	57	39	24
35	107	66	45	28	108	66	45	28
40	123	75	52	32	124	76	52	32
50	153	94	65	40	155	95	65	41
60	184	113	78	49	186	114	78	49
70	214	132	91	57	217	133	91	57

• AVAILABLE IN POLE TYPES

● APPROX % RELATIVE LINE LOSS TO LAMP WATTAGE BASED ON 150 FEET OF COPPER PER STANDARD

THE ABOVE TABLES FOR 20 AMPERE STRAIGHT SERIES CIRCUITS (NON INDUCTIVE LOAD) ARE BASED ON APPROXIMATE PERCENT RELATION OF I^2R LINE LOSSES TO LAMP WATTAGE AS INDICATED, BASED ON AN AVERAGE OF 150 FT OF WIRE PER STANDARD

FOR LOCAL CONDITIONS WHERE THE PERCENTAGE RELATION OF I^2R LINE LOSSES DIFFERS TO THAT GIVEN IN TABLES, APPLY FORMULA $\frac{\text{KW CAPACITY-K}}{\text{LAMP WATTAGE}}$.

K = LOCAL CALCULATED I^2R LINE LOSSES

Fig. 3. Load and Cost Data for an Analysis of Circuit Performance. In the tables are shown the number of lamps which can be operated from the transformers under various conditions

system, as consideration should be given to the advantages of the pole-type automatic system previously mentioned. It would appear, therefore, that the lamp capacity analyses should be made on the pole-type automatic distribution system rather than on the non-automatic station-type distribution system, since the former is generally preferred for overhead

The cost of different sizes of aerial cable and individual lamp transformer capacities is given in

Fig. 3, so that cost analyses may be worked out to determine the most economical system, depending on local conditions, etc. The cost of constant-current transformers per kilowatt are approximately the same for both 6.6 and 20-amp. secondary circuits, so that this item of cost is common for both systems and can be excluded in a comparison of the systems.

There are obviously many points of electrical similarity between underground and overhead systems of the same type; consequently, considerations of the two would involve comments and conclusions which would be likewise quite similar, or even identical. Hence, what follows is in a sense a repetition; but necessary for the sake of completeness.

Each of these systems of street-lighting distribution has certain merits that are not possessed by the other, and, in consequence, the choice of system should be based upon a comparison of their respective merits with regard to each installation under consideration. It is hoped that the foregoing description and the following analysis will materially assist in making an advantageous choice for any given set of conditions.

Advantages of the 6.6-amp. Series Lighting Circuit with Individual Lamp Transformers

Low voltage to the lamp.

Line losses with 6.6-amp. approximately 1/10 as great as the corresponding losses in a 20-amp. circuit.

From the standpoint of standard lamp sizes, there are more sizes available for 6.6-amp. circuits than for 20-amp. circuits.

Lamp outages do not interrupt the high-tension series circuit and the burned-out lamps are therefore readily located.

Elimination of film cutouts on the main series circuit.

Protection of lamps from surges.

Advantages of the 20-amp. Series Lighting Circuit

Voltage of the constant-current secondary series circuit is less than one-third that of a 6.6-amp. circuit.

The prevailing circuits permit the straight 20-amp. circuit and lamp to be used economically without the necessity for an investment in a special transformer for each lamp.

A larger number of lamps can be installed on the circuit because of the elimination of the inductive transformer load.

Simplicity of installation due to the elimination of individual-lamp transformers.

Disadvantages of a 6.6-amp. Series Circuit with Individual-lamp Transformers

Individual-lamp transformers involve an added investment cost per unit.

Cable connections to transformers are a possible source of trouble arising from poorly wiped joints.

Transformers represent an inductive load, reducing the lamp capacity of the constant-current transformer. That is, it lowers the power-factor of the system.

Disadvantages of a 20-amp. Straight Series Circuit

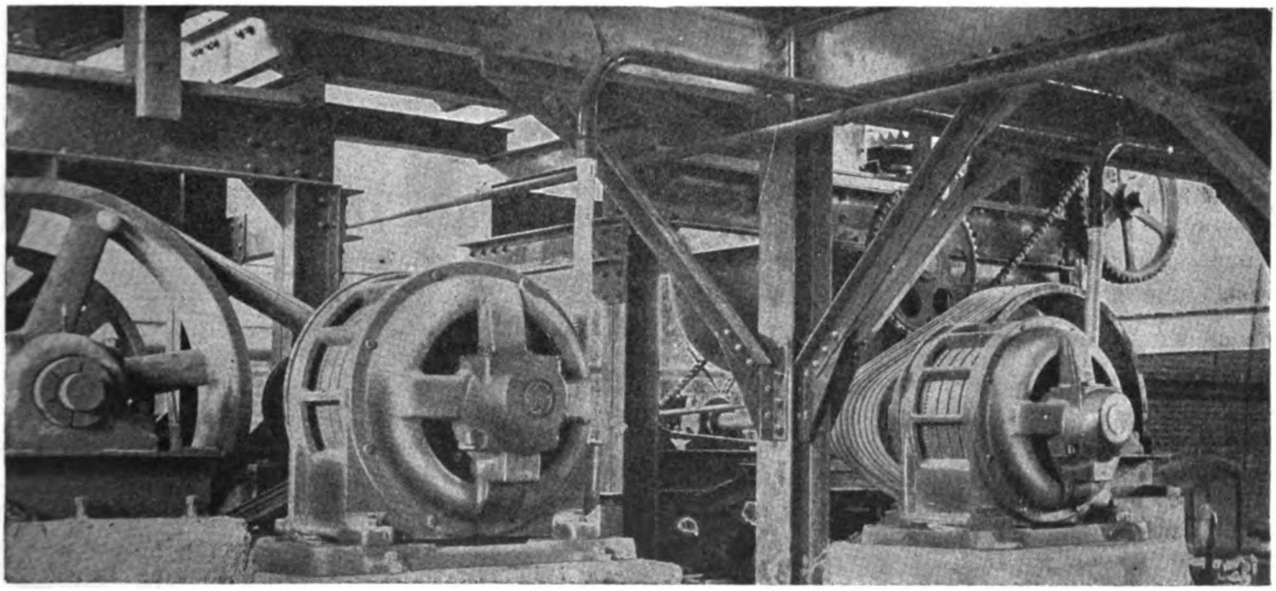
High I^2R losses in line.

More lamp outages caused by failure of improper film cutouts.

High voltage to the lamp.

More lamp failures due to surges.

Electric Motors in a Brick Plant



The Scope and Problems of Modern Physics

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(This contribution is based on a talk given by Prof. Karapetoff at Schenectady, N. Y., before the Advanced Class in Engineering of the General Electric Company

BY modern physics is meant here that portion of the science which deals with atoms, electrons, quanta, and radiations. No adequate classification of the subject has been given as yet, like the division of the classical physics into mechanics, heat, light, sound, electricity, and magnetism. One reason is that the very purpose of many endeavors is to connect different phenomena by a general underlying theory. Another reason is that the new elements (electrons, atoms, ions, quanta of radiation, etc.) hardly ever enter into a phenomenon singly, but always in combination with at least one different kind of element. Therefore, it is not possible to subdivide the subject into a study of electrons, study of atoms, etc.

Most physicists work in a definite and rather narrow domain of the subject, and the general scope and classification of modern physics is of comparatively minor interest to them. However, for an engineer who is interested in applying physical laws to practical problems, a general knowledge of the scope of modern physics is of importance. A young engineer who decides to devote at least part of his effort to a study of modern physics should obtain a bird's eye view of the whole field before choosing a particular topic. A few enumerations of topics and problems as given here, from different points of view, may help those interested in a preliminary orientation. General books on the subject should be consulted for further details. (See list of references at end of article.)

Electrons

There are many phenomena and problems in which electrons enter in combination with atoms, ions, magnetic or electric fields, etc. Yet a particular investigator may be primarily interested in electrons as such and regard the rest of the factors as given, known, or auxiliary. From the point of view of electrons, as an object of study, the following topics and problems may be mentioned: Electric charge on an electron, its mass, measurement of velocity, and deflection by an electrostatic or a magnetic field; electron spin as a cause of magnetism; wave properties of electrons in reflection and in passing through matter; collision with atoms and the resulting excitation and ionization; function of electronic streams and space charges in arcs, in glow discharges, and sparkovers; electrons as they enter into the structure of atoms and molecules; relation between electrons and spectra; photo-electricity or emission of electrons by incident light; thermionic emission of electrons; explanation of electric and thermal conductivity of metals by electrons; motion of electrons at high velocities and the necessity for a relativity correction; electronic phenomena in discharges in highly evacuated tubes; luminescence, cathode-ray beams, radio-activity, beta rays and disintegration of elements, degeneracy of electronic gas, production of x-rays by electronic bombardment, chemical affinity of elements explained on the basis of electronic orbits; electrons and the quantum theory, electronic mobility under different conditions, diffusion, and recombination.

Atoms and Molecules

Those primarily interested in atoms and molecules may consider electrons and radiations as secondary and known factors. Among problems of interest to such physicists the following may be mentioned: Wave theory of matter; selective reflection from surfaces of crystals; interaction with electromagnetic waves (refraction, absorption, dispersion); ionization and excitation of atoms; line spectra and band spectra; photo-electric emission and thermionic emission; isotopes, viscosity, magnetic properties, electrolytic and gaseous conduction; luminescence, statistical mechanics of gases; crystal structure, x-rays of different substances; chemical affinity on a physical basis; radioactivity; specific heats as bearing upon the molecular structure; applications of the quantum theory; dielectric behavior.

Ions

An ion is a small particle positively or negatively charged. Thus, an electron is the simplest possible negative ion; an atom which has lost one or more of its electrons is a positive ion. Sometimes ions are in the nature of clusters containing several molecules and an excess of positive or negative charge. Those interested in ions may study one of the following topics: ionization phenomena in gases and in liquids; glow discharges, arc and sparks; ionic spectra; conductivity of gases and electrolytes; luminescence, chemical affinity, radio-activity, mobility of ions; properties of atoms stripped of one or more electrons.

Electromagnetic Waves and Radiations

While the original electromagnetic theory of light, as given by Maxwell, belongs to classical physics, yet the advent of electrons, quanta, and other concepts of modern physics has greatly enlarged the scope of the subject, especially where interaction between radiation and matter takes place. The following topics may be mentioned: Behavior of electromagnetic waves in matter (reflection, refraction, polarization, dispersion, and absorption); excitation and ionization of atoms by ultra-violet light and by x-rays; production of photo-electric effect; thermal radiation as a basis for the new quantum statistics; radiation and the theory of relativity, photo-chemical activity, gamma rays, x-rays, penetrating cosmic radiation; corpuscular properties of light quanta (photons).

An Alphabetical List of Topics

Since the foregoing classification is somewhat artificial and involves a repetition of topics under the several headings, an alphabetical list of topics is given also. Of course it is far from being complete, and merely represents the principal topics to which the writer's attention has been called on different occasions. At the same time, since his task has been to establish as close a connection as possible between modern physics and the most important problems in electrical engineering, it may be assumed with some certainty that the topics listed are among those which are of growing importance, either in specific applications or in general understanding of the nature of matter and energy.

A perusal of this list will give a general idea of the scope of the subject; and in many topics a relationship to some problems in electrical engineering is fairly evident. Thus, the subject of arcs finds its application in circuit-breakers and arc furnaces; the theory of dielectrics is a foundation for the design of insulation; electronics, ionization, and thermionic emission form a basis for the operating characteristics of various types of vacuum tubes, etc.

Space does not permit a detailed description of the meaning and scope of all the items mentioned. The primary purpose of the list is to create interest among young engineers in whatever topics in physics may come the nearest to their particular engineering problems. The science and art of engineering can progress only through a more detailed knowledge of the laws of nature. What is pure physics today may be engineering tomorrow. The profession expects young engineers not only to become familiar with the accumulated practical experience of the past, but to draw on the new advances in physics, chemistry, mathematics, and mechanics as well.

The alphabetical list is as follows:

Arcs
Astrophysics
Atom, influence of electrostatic and magnetic fields upon
Atom, structure of
Chemical affinity from a physical point of view
Conductivity, electric
Conductivity, thermal
Crystal structure
Dielectrics, gaseous, liquid, solid
Dielectrics, breakdown
Dielectrics, absorption and dielectric loss
Diffraction of electrons and atoms from crystal surfaces
Electrons, properties of
Discharges, glow, streamers, sparkovers
Electromagnetic theory
Energy, nature of and quantization
Energy, transformation into matter and *vice versa*
Ionization phenomena
Isotopes
Luminescence, phosphorescence, fluorescence
Magnetism, nature of, electron spin, quantum theory of
Molecular structure
Photo-electricity
Quantum theory
Radioactivity and atomic disintegration
Radiations, their effect upon atoms
Reflection of electrons and atoms from crystal surfaces
Relativity, theory of, in its application to physics
Specific heats as bearing upon molecular structure
Spectroscopy as a powerful tool in the study of atoms and molecules
Statistical mechanics and the new principle of uncertainty
Thermal radiation and the new quantum theory
Thermionic emission
Viscosity and molecular structure
Waves, electromagnetic, their properties and quantization
Wave mechanics of matter
X-rays

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A Study of Crystal Structure and Its Applications

PART XIV

THE HIGH-VOLTAGE LAUE METHOD FOR THE DETERMINATION OF CRYSTAL ORIENTATION

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GLANCING beam x-ray methods, for determining crystal orientation, can be applied only to specimens in which the surface orientation is representative of the interior orientation. If this is not the case, either the surface layer must be removed by etching, or some other method of x-ray analysis must be adopted. Etching is frequently undesirable. A case of this sort recently encountered was a lot of silicon-steel single-crystal specimens which had been grown by recrystallization from polycrystalline strips (179) and had then been machined to certain specified dimensions. Precise measurements of these dimensions on a specimen with etched surfaces would have been impossible.

The Laue method can be advantageously employed for the determination of the interior orientation in such cases. This method is also of value for those specimens which, because of size or other characteristics, are not adapted for oscillating crystal methods. The main disadvantage of the method is the long exposure required for producing sufficient detail on the film if it is carried out with the tube voltages ordinarily employed in crystallographic work. This disadvantage becomes much more serious if more than one photograph is to be obtained from one specimen. In the method of orientation determination about to be described, three or four photographs may be necessary from some specimens. With ordinary voltages, the time required for such a process as this may easily become prohibitive.

Of the previous methods for the determination of crystal orientation by the Laue method, only two need be considered here. The original procedure is due to Gross, (180) who obtained the Laue pattern of highest symmetry from a crystal by means of a series of photographs taken with differing angles of incidence between the x-ray beam and the face of the specimen. Much shorter from the point of view of the laboratory is the method of Schiebold and Sachs, (181) in which the spots on a Laue photograph are plotted on a stereographic projection, from which the orientation of the specimen is obtained by comparison of this projection with a standard. This method has been used in this laboratory for orientation determinations, and in some cases it has been very successful. It possesses the objection that many times it becomes impossible to identify the spots positively, because the stereographic projection of many of the spots lie so close together.

Statement of Method

The long time of exposure demanded by the Laue method is necessary because of the absorption of the x-rays by the material which is being penetrated. This objectionable feature can be removed if higher-voltage x-rays are employed, since such rays are more penetrating. (182) By the aid of the combined accelerating power of high-voltage x-rays and intensifying screens, satisfactory Laue photographs have been obtained from steel specimens with remarkably short times of exposure. (183) Because many photographs can thus be obtained from a specimen within a convenient interval of time, the task of ascertaining the actual orientation of a crystal is much simplified.

For solving these photographs, use has been made of the gnomonic projection. The gnomonic projection is particularly suitable for this work because it is easily drawn, and also because the scale is so open in the regions covered by the photographs that positive identification of the planes producing reflection can be easily made. This projection possesses the disadvantage of extending to infinity in all directions, but this disadvantage disappears if the proper mathematical procedure is employed for securing the necessary rotational data from Laue photographs.

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(179) van Liempt, *Tech. Pub. A.I.M.E. No. 15* (1927).

(180) Gross, *Centr. Mineralogie, 52* (1920).

(181) Schiebold and Sachs, *Z. Krist, 63*, 34 (1926).

(182) A. H. Compton, "X-rays and Electrons" (D. Van Nostrand Co., 1926). 180-185.

(183) For similar results as to necessary times of exposure, see St. John, *Trans. A.S.S.T. 13*, 485 (1928).

References made to material hitherto published in this series of articles may be readily located from the following table:

Part	*Issue*	*Figs.*	*Equations*	*Tables*	*Footnotes*
Part I	Nov., 1924 p. 742	1 and 2	1 to 16	I and II	1 to 21
Part II	Dec., 1924 p. 795	3 to 10	17 to 32	III	22 to 27
Part III	Feb., 1925 p. 129	11 to 22	33 to 37	IV	28 to 42
Part IV	Apr., 1925 p. 258	23 to 28	38 to 41	None	43 to 48
Part V	May, 1925 p. 342	29 to 35	None	None	49
Part VI	Aug., 1925 p. 286	36 to 51	42	V to VII	50 to 58
Part VII	Oct., 1925 p. 721	52 to 59	43 to 47	VIII and IX	59 to 65
Part VIII	Feb., 1926 p. 118	60 to 67	48	X to XIII	66 to 82
Part IX	Apr., 1926 p. 274	68 and 69	49 to 56	XIV to XXVI	83 to 117
Part X	Aug., 1926 p. 580	70 and 71	57 to 66	XXVII to XXXI	118 to 131
Part XI	Sept., 1928 p. 496	72 to 77	67 to 84	XXXII and XXXIII	132 to 139
Part XII	Nov., 1928 p. 612	78 to 92	85 to 98	XXXIV and XXXV	140 to 162
Part XIII	Oct., 1929 p. 552	93 to 97	None	None	163 to 178

This mathematical procedure is greatly simplified if a Laue photograph can be obtained which shows some symmetry; two-fold symmetry is sufficient.

Description of Apparatus

The apparatus employed in this method is essentially the same as that used in Laue experiments at ordinary potentials. The tube was a universal Coolidge tube of the type used for deep therapy. The target was of tungsten, inclined at approximately 45 deg. to the axis of the tube. The focal spot was about $\frac{3}{16}$ in. in dia. The tube voltage employed was 270 kv. peak. The tube current was not kept constant by a stabilizer, so that it varied between the limits of 4 and 7 ma. The average value was probably about 5 ma. The voltage across the tube was measured by a sphere gap. The spheres used were the highly polished 125 mm. diameter spheres made by the Victor X-ray Corporation. Mechanical rectification of the tube current was employed.

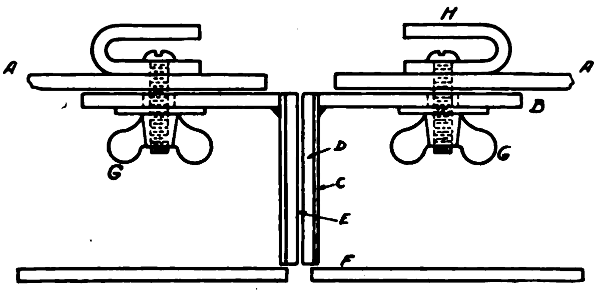

Fig. 98. Slit System for High-voltage X-ray Laue Work

The tube was enclosed in a box of ¼-in. lead. To reduce the number of openings in the box to a minimum, no blower was provided. In most of the experiments, none was needed, as the time of exposure was not sufficiently long to cause overheating of the tube. In longer exposures, the tube was run for 25-min. intervals separated by 5-min. rest periods.

The slit system for defining the x-ray beam was attached to one side of the lead box. The construction of this system is shown in Fig. 98. *A* is the side of the lead box enclosing the x-ray tube. The slit system was attached to this box by the bolts and wing-nuts *G*. The holes through which these bolts entered the lead box had to be capped by the thick lead pieces *H*. *B* is the base of the slit system, made out of ¼-in. lead. Into this a copper tube *C* was soldered, which was filled with lead *D*. The slit *E* was drilled through the lead. The slit employed in all this work was 25 mils in diameter and 2½ in. long. To make it possible to adjust this slit system easily for variations in the position of the focal spot of the tube, the holes in *B* through which the attaching bolts passed were made fairly large in diameter in comparison with the bolts. In practice it was found necessary to mount over the whole system the ¼-in. lead plate *F* through which was drilled a hole somewhat larger in diameter than the slit itself. This plate had to extend two or three inches beyond the edges of the film. It was found impossible to reduce x-ray leaks about the bolts and the soldered joint sufficiently so that this plate might be omitted.

The crystal under investigation was supported in the specially constructed goniometer shown in Fig. 99. The specimen was supported in the clamp and its height could be varied by means of the screw. The entire instrument was mounted on a table provided with levelling screws so that the instrument could be easily adjusted to cause the x-ray beam to penetrate the specimen at the common axis. The scales on the instrument were graduated in degrees. Interchangeable holders were provided, so that practically any size of specimen could be accommodated. The one shown was the one used with the majority of the specimens which were in ribbon form, ⅝ in. wide and 40 mils thick.

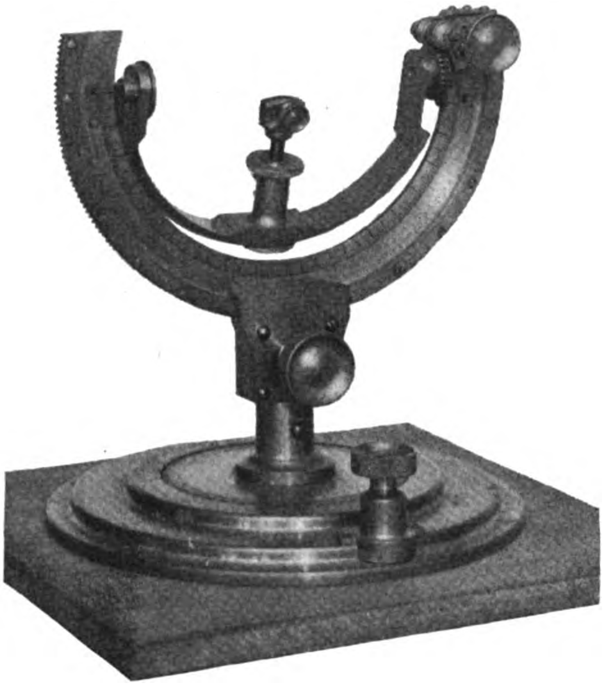

Fig. 99. Goniometer for Single-crystal Work

The device employed for holding the film is shown in Fig. 100. The films were the usual 5 by 7 Eastman Duplitized films which were used in conjunction with Patterson intensifying screens. The film and the intensifying screen were mounted together in a black paper envelope which was in turn enclosed in the envelope. The whole arrangement was locked in position by tightening the wing-nuts. When the film was being exposed to the x-rays, a sheet of ¼-in. lead was clamped over the back of the film-holder.

The distance from the target to the specimen was 20 in., that from the specimen to the film was 13.5 cm. (5.4 in.). The time required to produce satisfactory Laue photographs from crystals of silicon steel of the thickness mentioned above with the usual *Mo* $K\alpha$ radiation from a tube operating under an effective potential of 30 kv. was about 4 days. With the high-voltage x-rays employed in these experiments, the time of exposure was 15 min.

Experimental Method

The method employed in the determination of the orientation was to obtain first a Laue photograph from the crystal with the x-ray beam penetrating the crystal in a direction normal to the face of the specimen. From this photograph calculations were made of possible rotations which might be imparted to the crystal so that the Laue pattern obtained might possess some easily recognized symmetry. In practice, it was found that a photograph showing two-fold symmetry was sufficiently symmetrical. In this respect, the method described differs from that of Gross.(180)

In the case of silicon steel, the planes which, because of their largest interplanar distances, produce reflections closest to the zero beam impression on a film, belong to either the [110] or the [100] families. These planes are situated along zones such that when the crystal is turned to produce coincidence of their reflections with the zero beam impression, the photograph obtained must possess at least two-fold symmetry. In Fig. 101 is shown the gnomonic projection of a body-centered crystal with the (001) plane parallel to the plane of projection. In this position of the crystal the reflections from all of the [100] planes except the $(00\bar{1})$ plane would coincide with the zero beam impression, since their perpendiculars lie in the plane of projection, *i.e.*, the planes themselves are parallel to the x-ray beam. But the projection might be rotated along the line $k=0$, and still the $(0\bar{1}0)$ and the (010) plane projections would be found at infinity, or with their reflections coinciding with the zero beam impression. Therefore when a [100] plane reflection is brought into coincidence with the zero beam, the line of symmetry of the photograph coincides with either the line $h=0$ or $k=0$ on the gnomonic projection. For defining the position of the cube in space, it makes no difference which zone axis is taken.

Reference again to Fig. 101 shows that in the position of the body-centered cubic lattice shown, the projections of 4 [110] planes are to be found at infinity; therefore, the reflections of these planes coincide with the zero beam impression. Similar reasoning to that above also shows that when a [110] reflection is brought into coincidence with the zero beam impression, the line of symmetry of the photograph lies along either of the zone axes $\{\bar{1}10\}$ or $\{\bar{1}\bar{1}0\}$. Again, for defining the position of the cube in space, it makes no difference which zone axis is taken.

From the film obtained as previously described, calculations are therefore made of the rotations to be imparted to the specimen in order that different spots of the original Laue photograph may be brought into coincidence with the zero beam impression. If either a [100] or a [110] spot is thus affected, the resulting photograph will show at least two-fold symmetry. These spots may be expected fairly close to the zero beam impression of the original Laue photograph, and, in practice, it has never been found necessary to consider those more than a small angle away from the zero beam. The line of symmetry thus found will be located perpendicularly to the axis about which the crystal was rotated.

To find the necessary rotation to be imparted to the crystal, the angles α and β had to be known (Fig. 102), since owing to the manner in which the crystal was mounted in the goniometer, rotation had to take place about the axes E and F. Consider the spot B produced on a film on which the zero beam impression is located at A. Then

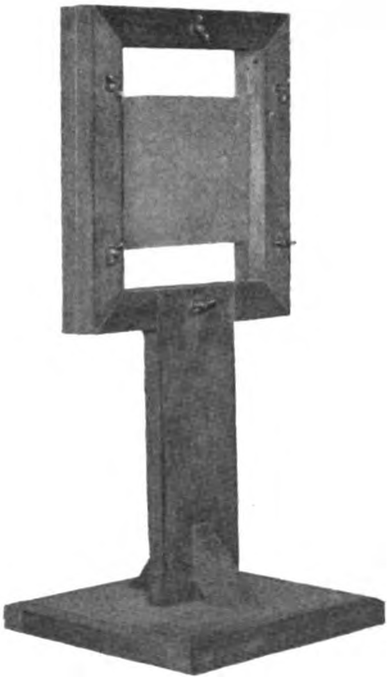

Fig. 100. Film-holder

$$DB/CD=DB\cos\beta/CA=\tan\alpha \qquad (99)$$

$$AD/CA=\tan \qquad (100)$$

In accordance with the laws of reflection, the amount of rotation to be imparted to the specimen to bring B into coincidence with A is $\frac{1}{2}\alpha$ and $\frac{1}{2}\beta$ respectively.

With the crystal turned into this new position, another Laue photograph was made. If this photograph showed two-fold symmetry, no more were made, but if it did not, another spot on the original Laue photograph was tried, in the same manner. In these Laue photographs it was important to have enough spots present so that no false impressions of symmetry were created. In some cases only one or two spots would destroy the apparent symmetry of a whole pattern.

When a symmetrical photograph had been obtained, the identification of the spots was undertaken. This was accomplished by considering the symmetrically placed spots closest to the zero beam in a zone which appeared complete on the film. The Bragg reflection law(184) was used to show what planes could possibly produce reflection at the observed angle from the zero beam. Choosing from this list of possibilities the planes which actually produced the reflections was accomplished by measuring the angles between the spots on the film and, from these, calculating the angles between the perpendiculars of the planes themselves. These values were compared with the calculated angles between the perpendiculars of the suspected planes.

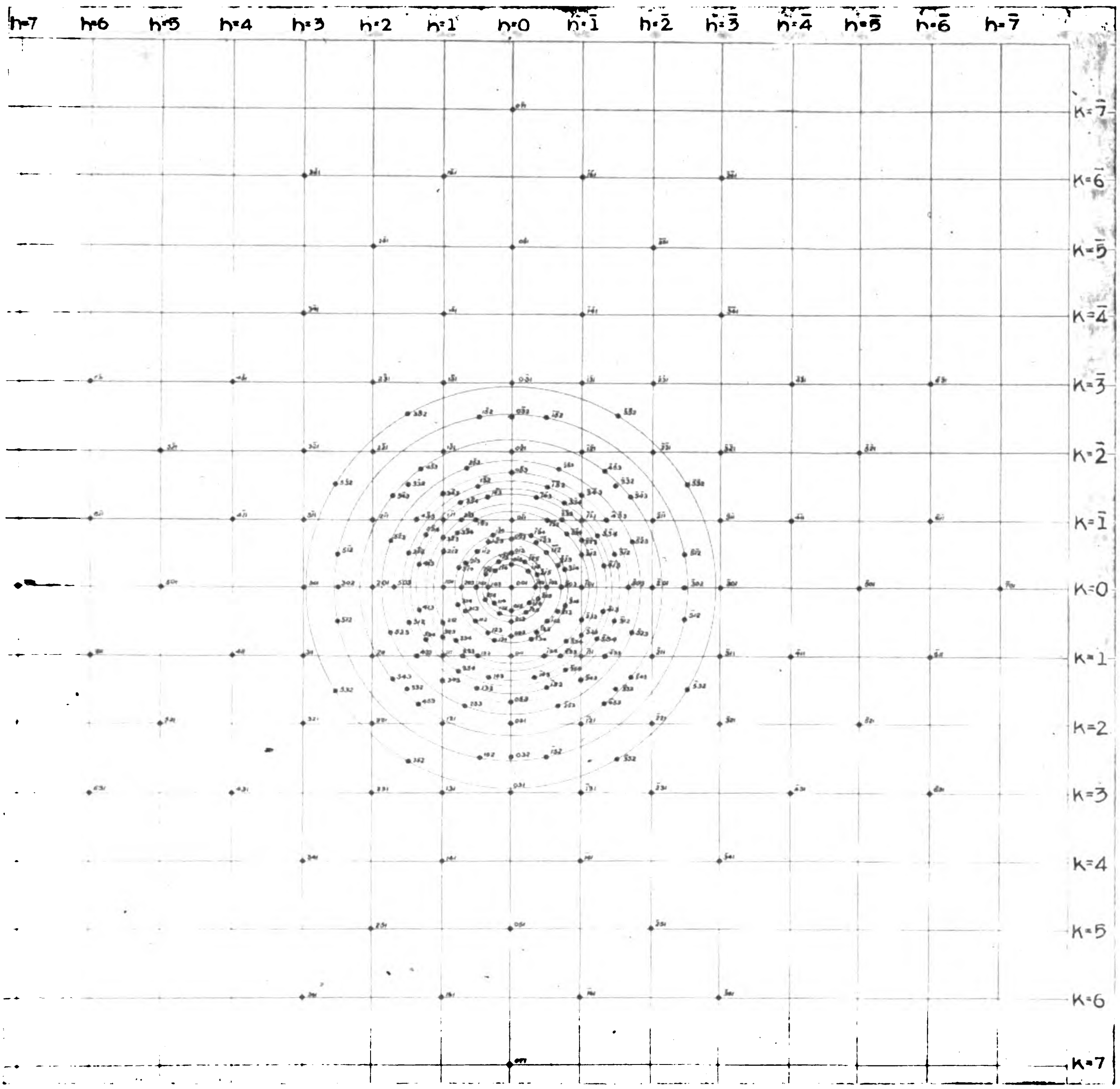

Fig. 101. Gnomonic Projection of Body-centered Cubic Crystal, X-ray Beam Parallel to Z-axis

The method of calculating the angles between plane perpendicular from the spots produced by x-ray reflection from the planes is shown in Fig. 103. Let *ABCD* represent a Laue film lying on the plane of the gnomonic projection *EFGH*. *JK* represents the line of symmetry. *L* and *M* represent two spots symmetrically placed about *JK*; *O* represents the zero beam impression of the film. The crystal is located at *N*. *P* and *Q* represent the gnomonic projections of the spots *M* and *L* respectively. The angle *LOM* will be the angle between these spots as measured from the film. Let it be called δ. Then the angle *JOM* will be $\frac{1}{2}\ \delta$, and from the manner of drawing the gnomonic projection, this will also be the value of the angle *POR*. In accordance with the usual custom of naming the angles, *ZONM* will be called 2θ, and, therefore, ONP will be designated as $90-\theta$.

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(184) Davey, General Electric Review, 27, 742 (1924).

The following relations are seen to exist between the different lines and angles on the plane:

$$PR = OP \sin \tfrac{1}{2}\delta \qquad (101)$$

$$OP = NP \cos \theta \qquad (102)$$

$$PR = NP \sin \tfrac{1}{2}\eta \qquad (103)$$

From Equations (101) and (103) it follows that:

$$\sin \tfrac{1}{2}\eta = \frac{NP}{OP} \sin \tfrac{1}{2}\delta$$

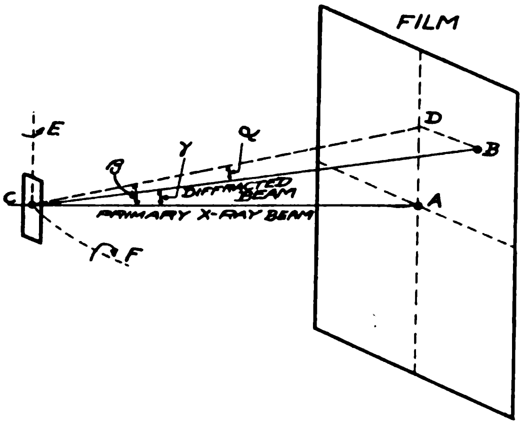

Fig. 102. Method of Ascertaining Angles for Goniometer Adjustment

which by combination with Equation (103) becomes

$$\sin \tfrac{1}{2}\eta = \cos \theta \sin \tfrac{1}{2}\delta \qquad (104)$$

Since the angle $LOM = \delta$ can be measured on the film by a protractor, and the angle θ can be calculated from the film as shown in Fig. 102, where

$$2\theta = \gamma = \tan^{-1} BA/CA \qquad (105)$$

the angle η (Fig. 103) can be calculated. This angle η is by definition the angle between the plane perpendiculars corresponding to the plane reflections at L and M.

For arriving at the identity of the planes producing the spots L and M, the angle η is to be compared with the calculated values of the angles between the perpendiculars of the planes satisfying the Bragg reflection law for spots with the observed value of 2θ. Since these spots were observed on a symmetrical photograph, the line JK must coincide with either of the generalized zone axes $\{100\}$ or $\{110\}$, and the spots L and M must belong to the same family of planes. Consequently the number of possibilities which must be calculated is considerably reduced.

The symmetrical pairs of planes, whose perpendiculars subtend different angles, may be read off of the projection of Fig. 101 directly; and the angles between the perpendiculars may be calculated by means of triangles. In this process, many of the possible pairs are likely to be overlooked, and the resultant calculations are very tedious. It is preferable to make use of the following rules for symmetry and the following method of calculating the subtended angles.

The rules for symmetry about the two zone axes may be simply stated in the following forms:

(1). Planes symmetrically arranged about the $\{100\}$ zone axis will have their indices in the same order, but with the sign of one index changed.

(2). Planes symmetrically arranged about the $\{110\}$ zone axis will have the order of two of their indices reversed. The sign of the indices may be unaltered, or the signs of both of the reversed indices may be changed.

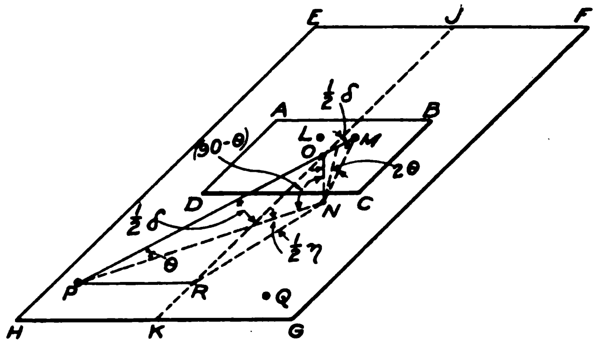

Fig. 103. Method of Calculating Angle Between Plane Perpendiculars from Laue Spots

As illustrations of the above rules, the case of the (312) plane may be cited. About the $\{100\}$ family of zone axes this plane is symmetrically placed with reference to the $(\bar{3}12)$ or the $(3\bar{1}2)$ planes. About the $\{110\}$ family of zone axes, this plane is symmetrically placed with respect to the (132) and the $(\bar{1}\bar{3}2)$ planes.

For calculating the angle between the perpendicular of a pair of planes use is made of the fact that, in the cubic system, for a plane described by the equation:

$$Ax + By + Cz + D = 0$$

the direction cosines of the perpendicular to the plane will be:

$$l = \frac{A}{\sqrt{A^2 + B^2 + C^2}}$$

$$m = \frac{B}{\sqrt{A^2 + B^2 + C^2}} \qquad (106)$$

$$n = \frac{C}{\sqrt{A^2 + B^2 + C^2}}$$

Let l_1, m_1, and n_1 be the direction cosines of the perpendicular of plane 1, and let l_2, m_2, and n_2 be these same quantities for plane 2. The angle between the perpendiculars will be denoted by ψ. Then

$$\cos \psi = l_1 l_2 + m_1 n_2 + n_1 n_2 \,^{(185)} \qquad (107)$$

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(185) Mellor: "Higher Mathematics for Students of Chemistry and Physics," Longmans & Co., 1919, pp. 127 ff., 132 ff.

Since *A*, *B*, and *C* in Equation (106) correspond to the ordinary plane indices, this method permits the calculation of all the angles which may possibly be subtended between the perpendiculars of any two families of planes, without reference to any projection. The angles calculated according to this method for all symmetrically disposed planes of steel whose interplanar distances are greater than 0.5 Å are given in Table XXXVI. In this table, the planes are arranged according to the axis about which symmetry is shown, and in order of increasing angle between perpendiculars.

After two of the spots have been either identified, or at least have had their identity suspected, by means of comparing the angles between their plane perpendiculars with the angles listed in Table XXXVI, a ruler may be laid across these spots on the gnomonic projection of Fig. 101, for the purpose of seeing what planes are to be looked for on the suspected zone. The angles between the perpendiculars of these planes are to be obtained either by calculation or by reference to Table XXXVI, and if agreement is found between all the calculated values and the values as measured from the film, and if the reflections are allowed by the Bragg reflection law, the identity of the zone is established.

Application to a Symmetrical Film

The application of the method to a symmetrical Laue photograph will be briefly described. The film reproduced in Fig. 104 is a photograph from a silicon-steel crystal obtained with the x-ray beam penetrating the specimen perpendicularly to the face of the specimen. This film was divided into quadrants by lines as shown in Fig. 102 which coincided in direction with the axes *E* and *F*, and the three spots nearest the zero beam impression were numbered as shown. The measurements made on the film to ascertain the positions of these spots, and the values of the angles calculated from them are shown in Table XXXVII. Positive values of the angles refer to rotations of the specimen either in the downward direction or toward the left to produce coincidence between spot and zero beam impression—negative values refer to the opposite directions.

TABLE XXXVI

ANGLES BETWEEN PERPENDICULARS OF PLANES SYMMETRICALLY DISPOSED ABOUT THE (100) OR (110) ZONE AXIS

Angle in Deg. and Min.	Planes	Zone Axis of Symmetry
0°	001, 011, 031, 021, 051	100
	001, 011, 211, 111, 411, 233	110
14° 50′	215–125	110
15° 56′	431–341	110
17° 19′	323–233	110
21° 2′	152–$\bar{1}$52 125–$\bar{1}$25	100
21° 47′	321–231 213–123	110
22° 37′	143–$\bar{1}$43 134–$\bar{1}$34	100
25° 50′	103–0$\bar{1}$3 103–013	110
27° 16′	141–141 114–$\bar{1}$14	100
31°	132–$\bar{1}$32 123–$\bar{1}$23	100
32° 12′	314–134	110
33° 34′	211–121	110
36° 52′	103–$\bar{1}$03 013–0$\bar{1}$3	100
42° 50′	251–$\bar{2}$51 215–215	100
44° 25′	312–132	110
45° 34′	521–251 215–$\bar{1}\bar{2}$5	110
48° 12′	121–$\bar{1}$21 112–$\bar{1}$12	100
48° 24′	413–143	110
50° 28′	233–$\bar{2}$33	100
51° 4′	114–$\bar{1}\bar{1}$4	110
60°	011–101	
	411–141	110
64° 37′	231–$\bar{2}$31 213–$\bar{2}$13	100
67° 23′	314–$\bar{1}\bar{3}$4	110
68° 29′	512–152	110
69° 4′	213–$\bar{1}\bar{2}$3	110
70° 32′	112–$\bar{1}\bar{1}$2 111–$\bar{1}\bar{1}$1	110
72° 5′	341–$\bar{3}$41 314–$\bar{3}$14	100
78° 27′	021–$\bar{2}$01	110
79° 31′	332–332 323–$\bar{3}$23	100
84° 15′	301–031 301–0$\bar{3}$1	110
87° 48′	501–0$\bar{5}$1	110
90°	101–$\bar{1}$01	100
	100–010	110
98° 13′	312–$\bar{1}\bar{3}$2	110
101° 33′	512–$\bar{1}\bar{5}$2	110
103° 20′	431–$\bar{4}$31 413–$\bar{4}$13	100
106° 36′	321–$\bar{3}$21 312–$\bar{3}$12	100
109° 24′	111–$\bar{1}\bar{1}$1	110
109° 28′	211–211	100
112° 53′	411–$\bar{1}\bar{4}$1	110
114° 9′	323–$\bar{2}\bar{3}$3	110
120°	211–$\bar{1}\bar{2}$1	110
126° 52′	201–$\bar{2}$01	100
129° 18′	521–$\bar{2}\bar{5}$1	110
129° 32′	332–$\bar{3}\bar{3}$2	110
131° 48′	521–$\bar{5}$21 512–$\bar{5}$12	100
141° 4′	411–$\bar{4}$11	100
141° 47′	321–$\bar{2}\bar{3}$1	110
143° 8′	301–$\bar{3}$01	100
151° 23′	501–$\bar{5}$01	100
152° 13′	431–$\bar{3}\bar{4}$1	110
177° 48′	413–$\bar{1}\bar{4}$3	110

TABLE XXXVII

POSITIONS OF SPOTS NUMBERED IN FIG. 104, AND VALUES OF THE ANGLES CALCULATED FROM THEM

Spot	Length AD (mm.)	Length DB (mm.)	Tan α	Tan β	α Deg.	β Deg.	$\alpha/2$ Deg.	$\beta/2$ Deg.
2	5.0	6.7	0.0495	0.0370	+2° 50′	+2° 7′	+1° 25′	+1° 4′
3	0.0	19.2	0.1423	0	−8° 6′	0°	−4° 3′	0°
4	39.4	21.3	0.1515	0.2918	−8° 37′	−16° 16′	−4° 19′	−8° 8′

Length $CA = 135$ mm.

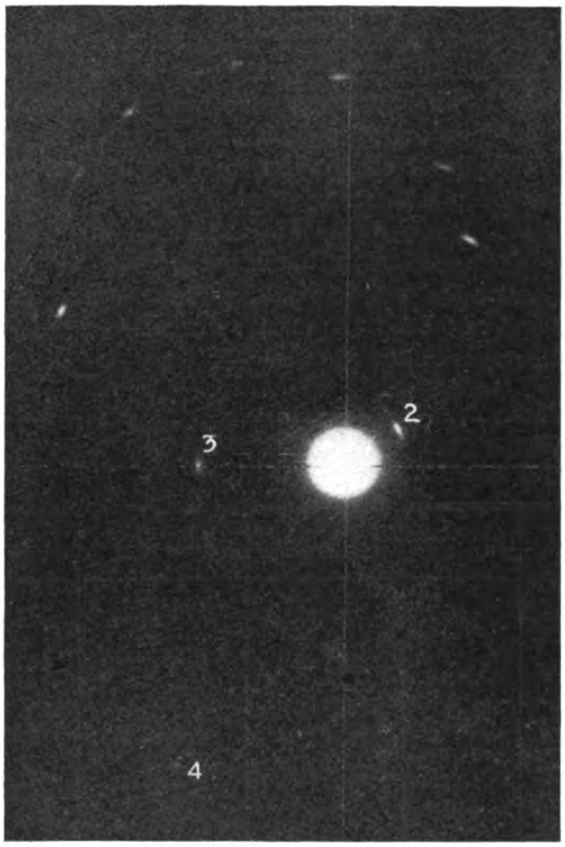

Fig. 104. Trial Photograph of Silicon Steel, Single Crystal

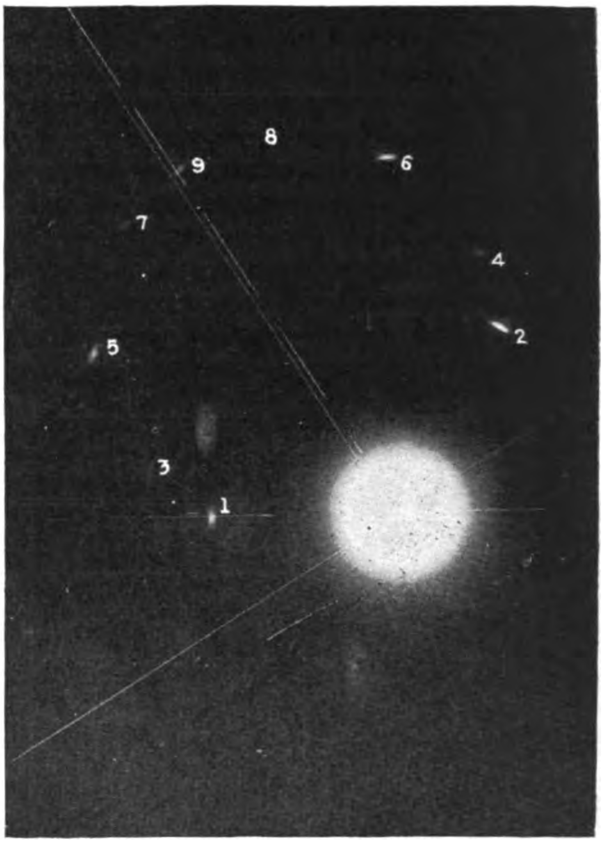

Fig. 105. Symmetrical Photograph of Silicon Steel, Single Crystal

Fig. 105 shows the photograph obtained when the crystal was so rotated that spot 2 was brought into coincidence with the zero beam impression. The line of symmetry is indicated. Consider the spots which are numbered (1) and (2). From the value of θ given for these spots in Table XXXVIII, it is possible to calculate the most likely identities of these spots if the efficient wavelengths in the x-ray beam are known. As a result of a large number of experiments with these high-voltage x-rays, it has been found that the most efficient minimum wavelength region for the production of spots is 0.112 Å, although the minimum wavelength present in the beam is much less than this. Consideration of the Bragg reflection law alone shows that any of the planes listed in Table XXXIX might have produced the reflections (1) and (2) of Fig. 105.

TABLE XXXVIII

POSITIONS OF SPOTS NUMBERED IN FIG. 105, AND VALUES OF ANGLES CALCULATED FROM THEM

Spot	Radial Distance (mm.)	Tan 2θ	2θ Deg.	θ Deg.
1	24.0	0.1778	10° 5′	5° 2′
2	27.3	0.2022	11° 26′	5° 43′
3	32.0	0.2370	13° 20′	6° 40′
4	35.2	0.2608	14° 37′	7° 18′
5	44.0	0.3259	18° 3′	9° 2′
6	46.2	0.3424	18° 54′	9° 27′
7	50.7	0.3755	20° 35′	10° 18′
8	51.5	0.3815	20° 53′	10° 26′
9	53.0	0.3926	21° 26′	10° 43′

Length $CA = 135$ mm. The radial distance is the length of the line AB (Fig. 102).

With a protractor, the angle between spots (1) and (2) is estimated as 120°, which after correction according to Equation (104) becomes 119° 14′. By comparison with Table XXXVI, it is seen that these spots were probably produced by the $(\bar{2}11)$ and $(1\bar{2}1)$ planes. The axis of symmetry is the zone axis $(\bar{1}10)$.

The angles between the other pairs of spots in the zone are shown in Table XL. By laying a ruler on the gnomonic projection of Fig. 101, the other planes listed in the table are shown to be on this zone. Calculations of the angles between their perpendiculars furnish the values given in the table. Agreement with the values of Table XXXVI for these planes is satisfactory. As the table shows, the reflections are possible in accordance with the Bragg reflection law. Consequently, the zone is identified.

TABLE XXXIX

PLANES WHICH MIGHT BE RESPONSIBLE FOR REFLECTION OF SPOTS 1 AND 2 (FIG. 105)

Plane	Interplaner Distance A°
110	2.03
100	1.43
211	1.17
110 (2)	1.01
310	0.905
111	0.825
100 (2)	0.715
411	
110 (3)	0.675
210	0.638

TABLE XL

ANGLES BETWEEN PERPENDICULARS OF PLANES PRODUCING PAIRS OF SPOTS IN ZONE OF FIG. 105

Pairs of Spots	Angle Measured from Film (Deg.)	Angle Corrected by Eq. (104) (Deg. and Min.)	Corresponding Angle from Table XXXVI (Deg. and Min.)	Identity of Spots
1–2	120°	119° 14′	120°	$1\bar{2}1$–$\bar{2}11$
3–4	98°	97° 2′	98° 13′	$1\bar{3}2$–$\bar{3}12$
5–6	60°	59° 8′	60°	$0\bar{1}1$–$\bar{1}01$
7–8	22°	21° 38′	21° 47′	$\bar{1}\bar{2}3$–$\bar{2}\bar{1}3$
9	0°	0°		$\bar{1}\bar{1}2$

The determination of the orientation of the crystal follows at once after the identity of the zone has been established. The method of procedure will be described in a subsequent installment.

(To be continued)

New High-voltage Underground Cable Installation

After continuous operation since August, 1927, the 12-mile 132,000-volt underground cable that connects the Hell Gate Generating Station of The United Electric Light and Power Company to the Dunwoodie Distributing Station of the Yonkers Electric Light and Power Company, has been duplicated through the laying of a second cable line of the same voltage. This new line, involving 190,000 ft. of 132-kv. single-conductor cable, went into operation on October 28, 1929.

The new cable contains a number of refinements or improvements resulting from operating experience with the older cable. The older cable, which at one step doubled the operating voltage for underground transmission, and which, with its hollow core filled with oil under pressure, was a new invention, was shipped from the factory with the oil drained off. It required refilling with oil after installation, which was a lengthy process requiring great care. The new cable lengths were shipped from the manufacturer with the core filled with oil supplied by temporary reservoirs mounted inside the cable reels. The jointing was done under oil pressure with the temporary reservoirs connected to the opposite ends and was accomplished with very little loss of oil.

In the first cable the permanent oil reservoirs were placed about one mile apart and the maximum oil pressure on the cable was approximately 30 lb. In the new cable, the oil reservoirs were placed about three to the mile and the maximum pressure is approximately 16 lb. The result of this decreased pressure has been a reduction in the amount of sheathing necessary. The first cable has a double sheathing. The inner layer of lead was reinforced by a spiral wrap of copper tape to give the strength necessary to stand the oil pressure, and over this is a second layer of lead to protect the copper tape from abrasion and corrosion. With the oil pressure cut in half, the copper binder and outer lead sheath are not necessary.

A carefully worked out plan of delivery of the cable reels from the factory obviated the necessity of trucking the reels to the cable storage yard, holding them there until needed and then retrucking them to the place of installation. Deliveries were made to freight yards nearest to the points of installation as needed, and thus trucked only once—directly to the job. The schedule was worked out so accurately that all cable was pulled in within 24 hours after being placed on the ground; and much of it went in on the day of delivery.

Industrial Electric Heating

PART XIII: THE THREE-PHASE ARC FURNACE (Cont'd)

By N. R. STANSEL
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THE maximum rate at which heat is lost from a furnace with closed doors occurs at the time that the charge attains its maximum temperature. This rate is the normal power receptivity of the furnace at that time and is higher than the average rate of heat loss over the period of time required to bring the charge to the molten state and to the maximum temperature desired. The estimate of this normal power receptivity value is a matter of experience and judgment. In Example 16, the estimated average power loss from the furnace is

$$\frac{5522\text{ kw-hr.} - 3700\text{ kw-hr.}}{2\text{ hr.}} = 911\text{ kw.}$$

We will assume that the power loss from the furnace when the maximum temperature of the charge is reached, *i.e.*, the normal power receptivity of the furnace under that condition, is 1200 kw.

We have limited the maximum power input to the furnace to 3120 kw. by our assumptions of furnace voltage and of the impedance of the furnace circuit. Hence the first requirement for the electrical apparatus for such an installation is that it be adjustable for a range of power input to the furnace of from 3210 kw. to 1200 kw.

By reference to Equation (51) it will be noted that the maximum power value P' of a given circuit can be reduced at will by decreasing the voltage. This method is used to reduce the value of P', as the normal power receptivity of the furnace declines as the temperature of the charge rises.

The general method of changing the voltage applied to the furnace is the use of taps in the primary winding of the transformer. In thus reducing the voltage we may or may not change the reactance of the circuit. Practice varies in this respect. As the reactance of the circuit is a factor in the maximum power value P' for any given voltage, we will compare the characteristic curves of our furnace circuit for several voltages below the normal voltage and for two conditions, *viz.*, (A) a reactance value that is the same for all voltages, and (B) the reduction of the reactance of the circuit in proportion to the reduction in voltage. In both cases the resistance of the circuit is assumed to have the same value and is not changed with changes in the voltage. These characteristic curves are shown in Figs. 163 to 166 inclusive; Curves A for constant reactance and Curves B for the reactance reduced in proportion to the reduction in voltage. The calculated values of P', I', cos ϕ', and θ' corresponding to these curves are given in Tables XLII(A) and XLII(B).

TABLE XLII(A)
REACTANCE CONSTANT

E (volts)	P' (kw.)	I' (amp.)	Cos ϕ' (p-f.)	θ' (efficiency)
225	3217	12,527	0.76	0.83
199	2517	11,081	0.76	0.83
173	1903	9,636	0.76	0.83
156	1541	8,672	0.76	0.83
138	1218	7,708	0.76	0.83

TABLE XLII(B)
REACTANCE VARIED

E (volts)	P' (kw.)	I' (amp.)	Cos ϕ' (p-f.)	θ' (efficiency)
225	3217	12,527	0.76	0.83
199	2774	12,318	0.78	0.82
173	2332	11,241	0.79	0.82
156	2038	11,586	0.80	0.78
138	1748	11,183	0.81	0.77
121	1470	10,736	0.83	0.74

As previously stated, it is not desirable, as a general rule, to operate a furnace at the maximum value of power input P' because of the comparatively low values of power-factor and electrical efficiency obtained at that input to the furnace. It is quite common to regard some minimum value of power-factor as the governing factor for the electrical operation of a furnace. We will assume in this case that this value of power-factor is 0.85. The values of power input, current, and electrical efficiency for different voltages and at that power-factor under the two reactance conditions are given in Tables XLIII(A) and XLIII(B).

The following table facilitates the location of material hitherto published in this serial:

Part	*Issue*	*Figs.*	*Equations*	*Examples*	*Tables*	*Footnotes*
Part I	Oct. 1927, p. 448	1 to 32	(1) to (8b)	1 to 3	I to III	(1) and (2)
Part II	Nov. 1927, p. 551	24 to 43	(9) and (10)	4 to 6	IV to VII	(3) to (13)
Part III	Dec. 1927, p. 600	44 to 57	(11) and (12)	8 to 11	VIII to IX	(14) and (15)
Part IV	Mar. 1928, p. 125	58 to 73	(13) and (14)	——	X to XX	(16) to (26)
Part V	Apr. 1928, p. 204	74 to 83	(15) to (21)	12 and 13	XXI to XXIII	(27) to (29)
Part VI	Sept. 1928, p. 485	84 to 99	——	14	XXIV to XXVI	(30) to (35)
Part VII	Oct. 1928, p. 560	100 to 113	(22) to (24)	15	XXVII and XXVIII	(36) to (41)
Part VIII	Dec. 1928, p. 662	114 to 138	(25)	——	——	(42) to (47)
Part IX	Mar. 1929, p. 162	139 to 144	(26) to (34b)	——	XXIX to XXXIII	(48) to (59)
Part X	May 1929, p. 278	145 to 150	(35) to (44)	——	XXXIV and XXXV	(60) to (65)
Part XI	Aug. 1929, p. 448	151 to 154	(45) to (50)	——	XXXVI to XXXVIII	(66) to (73)
Part XII	Feb. 1930, p. 123	155 to 162	(51) to (55)	16	XXXIX to XLI	(74) and (75)

Thus under the condition of a fixed value of reactance in the circuit and operation at a given power-factor, as in Table XLIII(A), we obtain the desired minimum input of power to the furnace with approximately 138 volts, *i.e.*, approximately 61 per cent of the "high" voltage. This, it will be noted, requires a reduction of current for each voltage reduction.

When the reactance is reduced each time the voltage is reduced as specified, the operation at the given power-factor requires the same value of current for each voltage. We find, as shown in Table XLII(B), that we must reduce the voltage below 121 volts to obtain the desired minimum power input to the furnace. Also, the lower the voltage the lower is the electrical efficiency of the circuit.

It seems reasonable to assume that the ampere rating of the electrical apparatus for this service should be based on the minimum permissible power-factor. It may not be deemed sufficiently conservative however, to assume any particular method of electrical operation. If in our example we take 10,500 amp. as the normal current of the circuit we have two factors of safety as regards the temperature rise of the electrical apparatus, *viz.*, the reduction of the secondary voltage during the heat cycle of the furnace, and the intermittent application of the current. (A certain period of time is required between heats for charging and pouring. During these periods the current is zero and the transformer is not excited.) Against these safety factors we have the condition of a fluctuating current, which varies at times between zero and the value attained with one or more of the electrodes in contact with the charge. We must also take into account the possibility of operation with the current corresponding to the maximum power value P', in this case 12,527 amp.

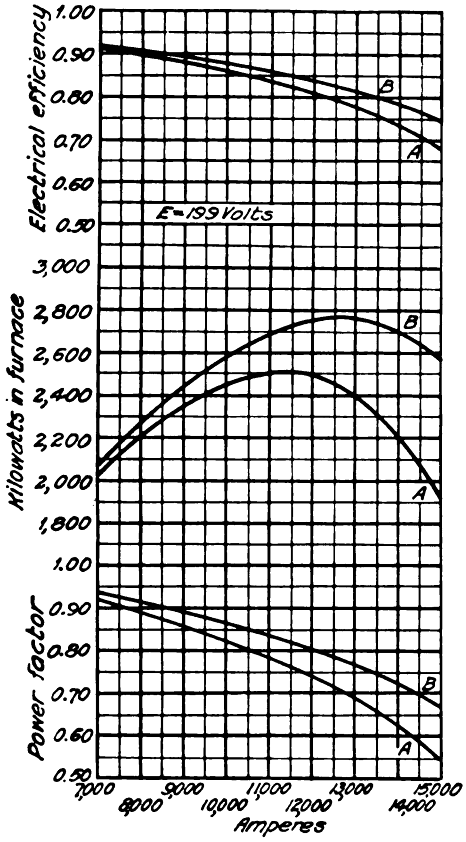

Fig. 163. Characteristic Curves of Furnace Circuit
A: Reactance Constant. *B:* Reactance Varied.

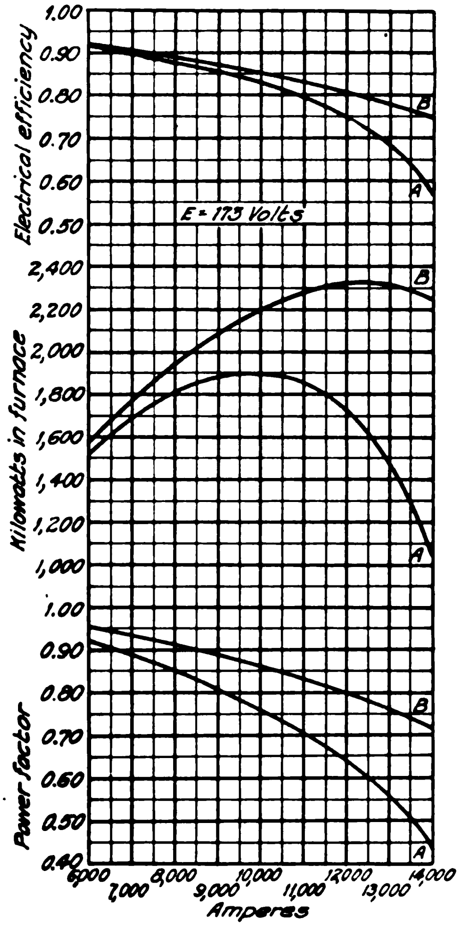

Fig. 164. Characteristic Curves of Furnace Circuit
A: Reactance Constant. *B:* Reactance Varied.

TABLE XLIII(A)

Power-factor 0.85. Reactance Constant

E	$P_{0.85}$ (kw.)	$I_{0.85}$ (amp.)	$\theta_{0.85}$ (efficiency)
225	3050	10,500	0.87
199	2400	9,500	0.87
173	1800	8,200	0.87
156	1500	7,400	0.87
138	1180	6,500	0.87

TABLE XLIII(B)

Power-factor 0.85. Reactance Varied

E (volts)	$P_{0.85}$ (kw.)	$I_{0.85}$ (amp.)	$\theta_{0.85}$ (efficiency)
225	3050	10,500	0.87
199	2650	10,500	0.86
173	2260	10,500	0.84
156	2000	10,500	0.82
138	1700	10,500	0.80
121	1443	10,500	0.77

On this basis the rating of our transformer is

$$10{,}500 \times 225 \times 1.73 = 4000 \text{ kv-a.}$$

This is 400 kv-a. per ton of molten metal holding capacity of the furnace.

A rule of thumb for estimating transformer ratings for arc furnaces states that the kilowatt rating at the specified power-factor should be from three to five times the average rate of heat loss from the furnace. There is much latitude in this rule and its use is a matter of judgment and experience with the particular type of furnace under consideration. In our case, this rule would give a transformer rating between 3200 and 5300 kv-a, depending on the value of the multiplier selected.

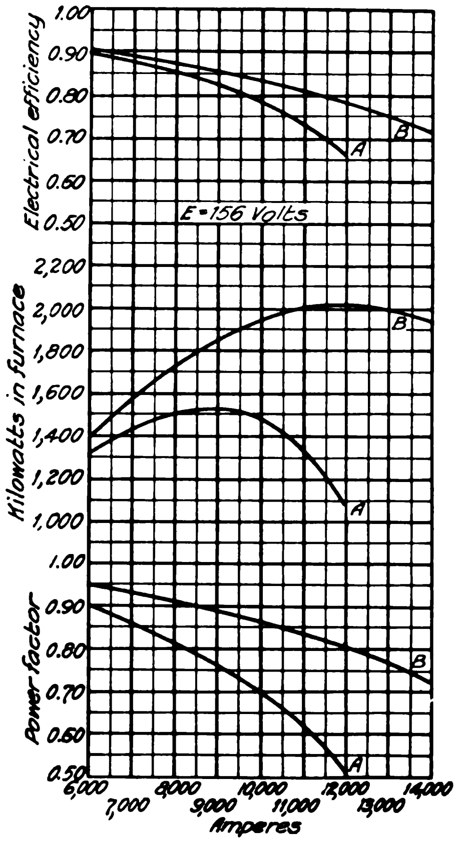

Fig. 165. Characteristic Curves of Furnace Circuit
A: Reactance Constant. *B:* Reactance Varied.

Within the limits already stated an increase in the kv-a. rating of the transformer for a given furnace decreases the length of the time required to bring the charge to the molten state and hence decreases the heat loss per ton of metal poured. The increase in the investment charge due to the larger electrical equipment should be compared with this gain by its use. This comparison is not so favorable for basic furnaces as for acid furnaces because of the influence of the refining period in basic operation on the total heat loss per charge.

The larger the transformer for a given size furnace the lower is its average load in per cent of the kv-a. rating over a period of operation; hence the lower its all-day efficiency. However, the efficiency of a transformer is high at all loads and varies but little with size. Thus the variation in transformer losses for different sizes of transformers is an unimportant factor in the consideration of the kv-a. rating of a furnace transformer.

Many rate schedules include a maximum demand charge and this—if present—may have some influence on the selection of the kv-a. rating of the transformer for a furnace installation. Rate schedules of different localities are not uniform. The proportion of the furnace load to the total load of the plant also varies for different installations. Thus it is necessary to examine each case to determine whether the maximum demand charge is a factor in the choice of the kv-a. rating of furnace transformer. If there is no objection from the production viewpoint to decreasing the furnace load at times during the day, that method can be utilized to avoid an undue effect of the maximum demand charge.

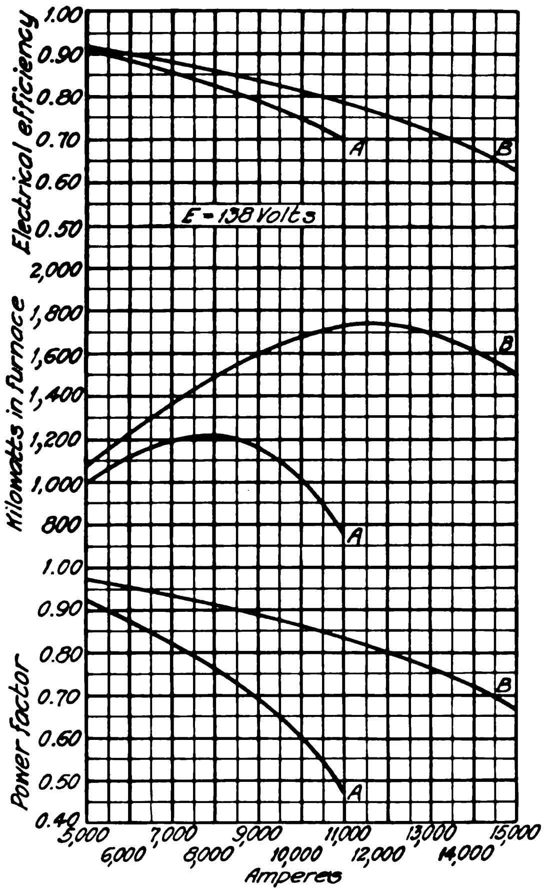

Fig. 166. Characteristic Curves of Furnace Circuit
A: Reactance Constant. *B:* Reactance Varied.

On the whole, there are so many factors which have an influence on the selection of the transformer capacity for a furnace installation that a rule or table of sizes can be only suggestive. A survey of present-day furnaces installations in this country is embodied in Table XLIV.

A chart (Fig. 167) from the Report of the Steel Committee of the Verein Deutscher Eisenhüttenleute by Kriz (76) represents the conclusions of that committee in regard to the transformer ratings best suited to different sizes of steel melting furnaces for installation in Germany. While industrial conditions abroad differ from the industrial conditions in this country these data of the German engineers are of interest in connection with the analysis of any arc furnace installation.

TABLE XLIV

Furnace Size (Tons holding capacity)	Transformer Rating (Kv-a. per ton holding capacity of furnace)
2	300-600
4	300-550
6	300-500
8	250-450
10	250-450
12	250-400
14	250-400
16	200-400
18	200-350
20	200-350

As stated in a previous paragraph—in Part XII—it is seldom that more than three voltages, designated as "high," "intermediate," and "low" operating voltages, are used in arc-furnace practice. In the early days of the three-phase furnace the sizes were small and only one operating voltage was used. Many furnace installations of this kind are in operation today. If the power input of the furnace is kept below the normal power receptivity of acid furnaces during the melting period only one operating voltage is needed. This, however, limits the rate of melting. The first step towards multiple-voltage operation was the use of two operating voltages, "high" and "low" in basic operation. Later, as the transformer size for a given furnace was increased, the "intermediate" voltage was added. As furnace sizes increase it is logical to expect a further extension in the use of the multiple-voltage principle. The added investment for switching equipment for an increase in the number of operating voltages becomes of less and less importance as the size of the furnace installation grows. The saving due to multiple-voltage operation is in an increased refractory life and a decrease in heat loss per ton of metal poured. In this connection it is of interest to compare arc-furnace operation with the operation of resistor furnaces. The same principle applies although refractory life is not a problem of the resistor furnace. With the latter type furnace the normal power receptivity curve of the furnace is followed by the use of intermittent applications of power as shown in Fig. 43, in Part II of this serial.

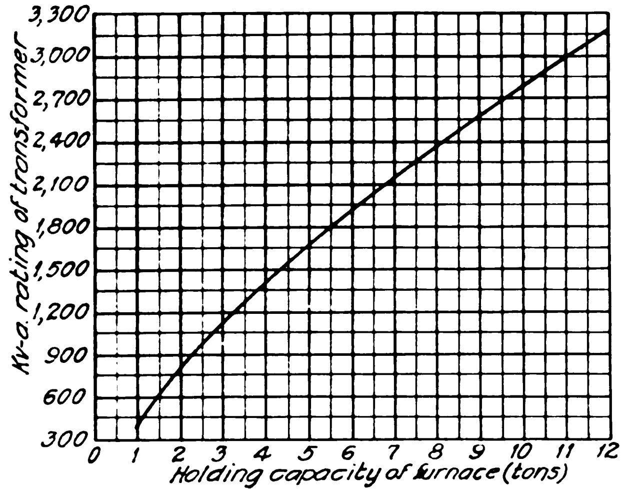

Fig. 167. Relation of Transformer Capacity to Holding Capacity of Arc Furnaces from a Study of German Engineers

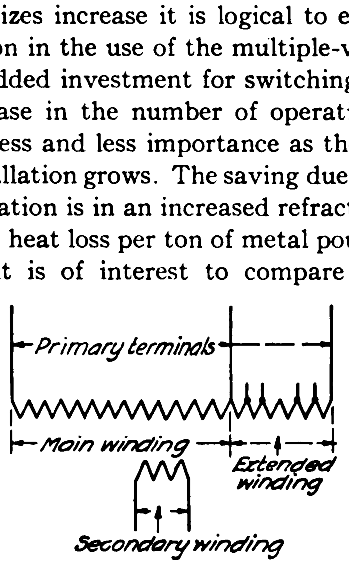

Fig. 168. Diagram of Transformer Windings

The secondary currents of three-phase arc transformers are comparatively large, and for this reason it is more convenient to place taps in the primary winding of the transformer to obtain the different secondary voltages. This requires extending the primary winding for the taps to obtain voltages below the "high" voltage. This arrangement is indicated by the diagram in Fig. 168. These taps are designated as "operating" taps. This term distinguishes these taps from the "regulating" taps usually placed in the primary winding of power transformers to provide for normal secondary voltage in case the primary voltage is above or below normal. The addition of regulating taps to furnace transformers is the exception rather than the rule. When used in furnace transformers, conservative design makes the area of the magnetic core sufficient for normal primary voltage on any tap. Thus such taps become in effect operating taps.

A certain degree of flexibility for each of the operating voltages is desirable, as no two furnaces are exactly alike. Furthermore, the conditions of operation may be changed at any time. This flexibility is obtained by the provision of more than one tap for the selection of each of the operating voltages.

The conditions affecting the connections of furnace transformers are the same as for power transformers. The delta connection of the primary is general practice. The secondary windings can be connected either in delta or in Y. In some cases the Y-connected secondary is required in order to obtain the neutral connection for the furnace.

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(76) *Stahl und Eisen*, Vol. 47, No. 16, p. 653.

In Fig. 169 is shown the diagram of the three-phase primary connections for tap changing to provide three operating voltages. The extension of the primary winding for the "low" voltage tap is not often used, as the "low" voltage can be obtained by changing the primary windings from delta to Y. A suitable location of taps to give the desired "low" voltage is selected close to the Y connection. The diagram of this arrangement is shown in Fig. 170. If the secondary windings of the transformer are Y-connected the method of switching indicated in Fig. 170 is still permissible, since with the primary windings connected Y on normal delta voltage the magnetic flux density is low, and the usual objections to the Y-Y connection for transformers are not so important.

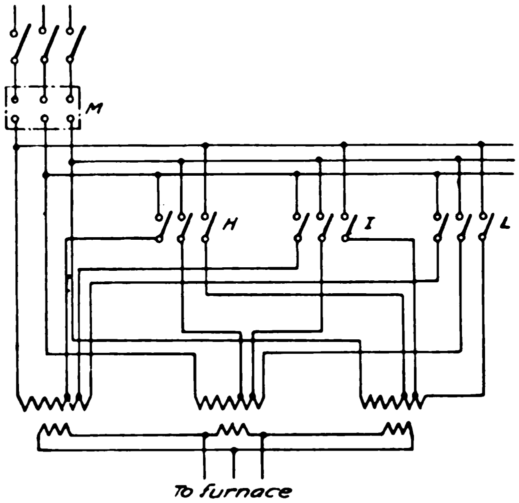

Fig. 169. Diagram of the Connections for Three Operating Voltages With Primary Winding of Transformer in Delta

M: Main Oil Circuit Breaker
H: "High" Voltage
I: "Intermediate" Voltage
L: "Low" voltage

We have used the "high" secondary voltage as the basis of the kv-a. rating of the transformer. The object of the taps in the extension of the primary winding is to reduce the power input to the furnace. Hence all of these taps can be reduced—kv-a. taps. As a general rule an "intermediate" voltage tap giving an "intermediate" voltage of about 70 per cent of the "high" voltage is a sufficient extension of the primary winding. This assumes that the "low" voltage is obtained by changing the primary windings from delta to Y. The "low" voltage required depends particularly on the method of operation as regards the reactance of the circuit, as shown with reference to Tables XLIII(A) and XLIII(B). As a rule, the "low" voltage needed is not less than can be obtained with the primary windings connected Y on the lowest intermediate voltage tap.

The physical size of a furnace transformer of a given kv-a. rating is determined by the kv-a. rating and the length of the extended winding. The area of the magnetic core is fixed by the magnetic flux with the primary connections on the "high" voltage tap. The extended winding, when in the circuit, increases the number of primary turns with a consequent reduction in the normal amperes in the primary winding. This makes it possible to progressively reduce the cross-section of the extended winding. However, it is more economical in construction to make the extended winding uniform in area with that of the main winding. The effect of the extended winding on the physical size of the transformer is an increase in that size approximately proportional to one-half the percentage increase in the total number of turns in the primary winding. Thus the use of the method of obtaining the "low" voltage by changing the connections of the primary windings from delta to Y is of material advantage as regards the cost of the transformer.

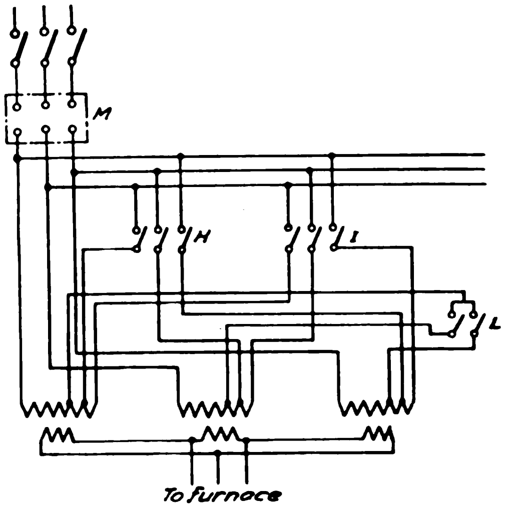

Fig. 170. Diagram of the Connections for Three Operating Voltages. The "low" voltage is obtained by changing the primary windings of the transformer from delta to Y

M: Main Oil Circuit Breaker
H: "High" Voltage
I: "Intermediate" Voltage
L: "Low" Voltage

The normal inherent reactance of furnace transformers ranges from 5 to 10 per cent reactive drop at normal rating; the exact value depends on the design in each case. Reactance values higher or lower than the normal can be obtained but may entail some sacrifice one way or another in the design.

Some of the features of the construction of furnace transformers are illustrated in Figs. 171 and 172. This type of transformer is characterized by the special bracing of the coils to obtain the mechanical strength needed on account of the widely fluctuating current, the extra insulation to guard against high voltages due to the distortion of the voltage wave forms by the arcs, and by the heavy secondary coil construction. A standard construction for the secondary windings is the use of multiple coils in each phase with both ends of each coil brought through the tank cover. Solid bar leads are used, and these are arranged in alternate positive and negative sequence so as to minimize losses and to avoid heating of the tank cover. The multiple connections of these coils and the three-phase connections of the secondary circuits—either delta or Y as the case may be—are made outside of the transformer tank.

The choice of the method of cooling a furnace transformer, *i.e.*, self-cooled, water-cooled, or forced-oil-cooled, is based on the same considerations as apply to installations of power transformers. The majority of furnace transformers, 750 kv-a. and above, are water-cooled.

The heavy bus bar construction of transformers for furnace service in sizes above 1000 kv-a. does not lend itself well to transformer design for outdoor installation. Also it is generally desirable to locate the transformer as near the furnace as practicable; this on account of the cost of the secondary bus and because of the impedance—particularly the reactance—of the secondary circuit, which is a factor in the maximum power value P', as in Equation (51). There is, of course, more freedom in the choice of the location of the transformers in smaller installations. These considerations generally lead to the use of indoor transformers for the sizes 500 kv-a. and above.

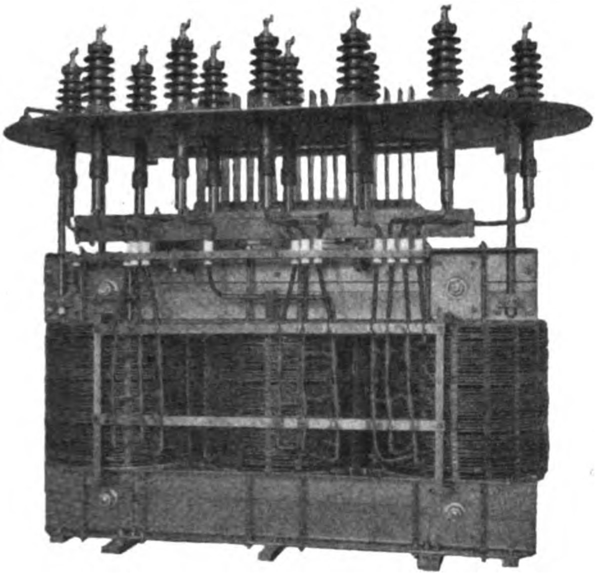

Fig. 171. Interior View, Primary Side, of a Three-phase Arc-furnace Transformer

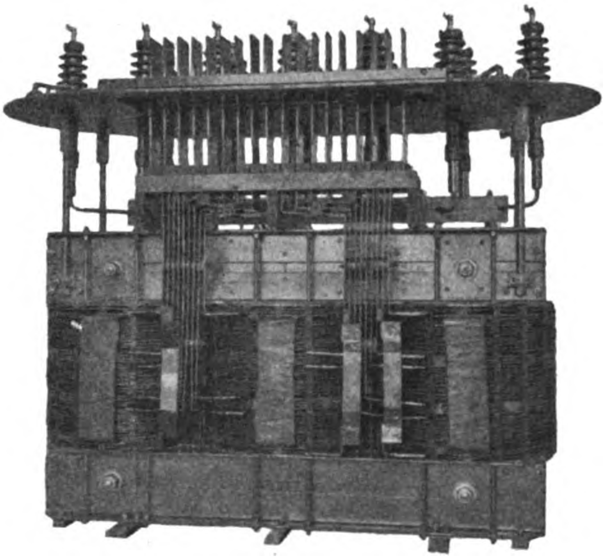

Fig. 172. Interior View, Secondary Side, of the Transformer Shown in Fig. 171

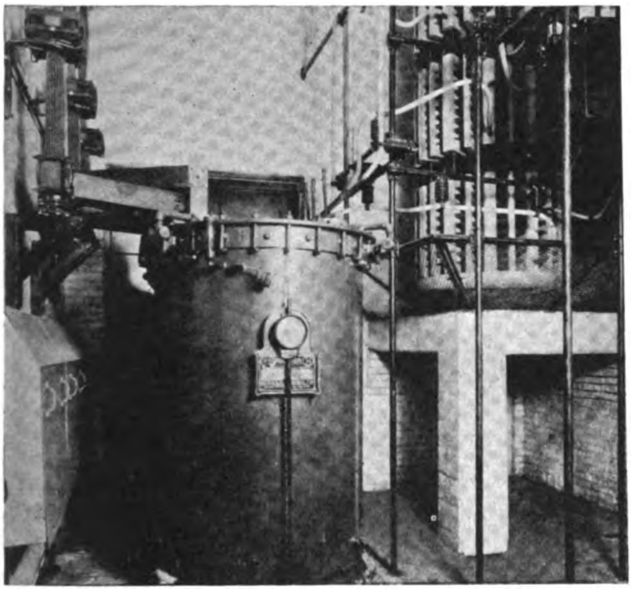

Fig. 173. Installation of a Three-phase Water-cooled Arc-furnace Transformer and Primary Air-core Reactors

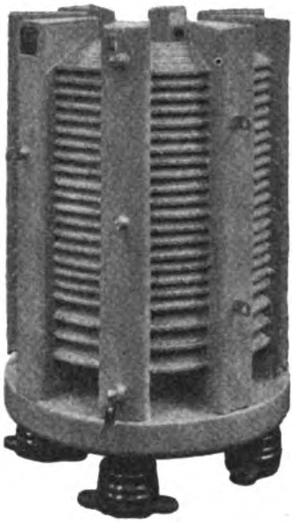

Fig. 174. Typical Single-phase Air-core Reactor

The space advantage and cost of the three-phase transformer as compared with three single-phase transformers generally favor the three-phase unit for furnace service.

A typical installation of a three-phase water-cooled arc-furnace transformer is shown in Fig. 173. The enclosure of the electrical apparatus of these installations is an advantage as regards protection and cleanliness. In large installations the space required for the wall between the furnace room and the transformer may be a disadvantage because of the consequent increase in the length of the secondary bus structure.

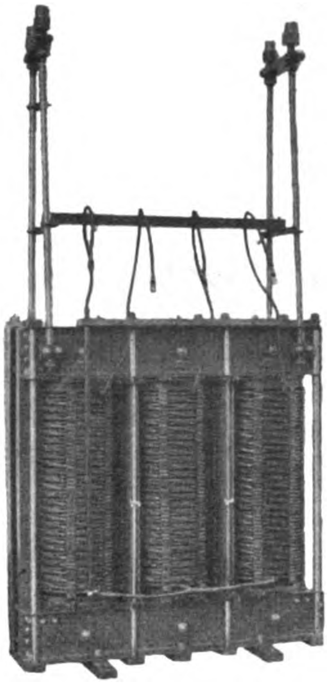

Fig. 175. Interior View of Iron-core Reactor

The total normal impedance of a furnace circuit is the sum of the impedances of the primary circuit between the point at which the primary voltage is held constant and the transformer, of the transformer, and of the secondary circuit including the effect of the resistance of the Y-connections of the arcs inside the furnace. It may be necessary to supplement this normal impedance by reactance to obtain sufficient stability in the operation of the arcs or to limit the short-circuit current to some value specified by the power supply system, or for both reasons. The value of this supplemental reactance is an individual matter in each case as there are no two furnace circuits alike. Small installations with low current values require more supplemental reactance than large installations. The reactance in the primary supply circuit is sometimes an important factor. For example, a furnace installation which included reactors was located at the end of a long primary circuit. The furnace operated satisfactorily with practically all of the reactor turns cut out. A rearrangement of the circuits of the power supply system brought the substation close to the furnace. It was then necessary to add the reactors to the furnace circuit.

The requirements of power supply systems regarding the effect of current variations on the voltage regulation vary. The size of the furnace installation with respect to other loads on the power system adjacent to the furnace installation is the important consideration.

Specifications for reactors for three-phase arc furnace circuits range from 40 per cent reactive drop at normal rating for the smaller installations (say, 500 kv-a. to 1500 kv-a.) to lower and lower values as the size of the installation increases. Reactors are seldom required for installations of 7500 kv-a. and above. Reactors are almost invariably installed in the primary circuit, because of the magnitude of the secondary current.

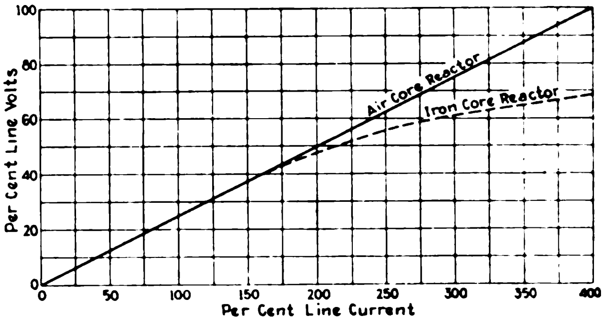

Fig. 176. Characteristic Curves of Standard Reactors

Typical reactors for this service are shown in Figs. 174 and 175. The choice between the two types, air-core reactor and iron-core reactor, is mainly a matter of first cost if the reactor is to be installed outside of the transformer tank. This also applies to the selection of three single-phase reactors or one three-phase reactor. High voltage and small current favor the iron-core reactor. The air-core reactor usually has the advantage up to around 13,200 volts. The characteristics of standard reactors of both types are shown in Fig. 176. The iron-core reactor is frequently placed inside the transformer tank. This gives a compact arrangement of apparatus but increases both the size of the transformer tank and the amount of oil required. Taps in the reactor windings provide for adjustments of the supplemental reactance to suit operating conditions and also for changing the value of this reactance when changing the operating voltage if that is desired.

(*To be continued*)

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

Arc Welding

Automatic Arc Welding of Thin Sheets. W. L. Warner.
A.S.M.E. Trans. (IS), Sept.-Dec., 1929; v. 51, paper no. 7, pp. 67-73.

Calculus, Operational

Heaviside Operational Calculus. John R. Carson.
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Daylight

Color of Daylight. A. H. Taylor.
Illum. Engng. Soc. Trans., Feb., 1930; v. 25, pp. 154-171.

Electric Arc

Calorimetric Study of the Arc. P. P. Alexander.
A.I.E.E., Jour., Feb., 1930; v. 49, pp. 138-141.

Electric Drive

Flange- or Foot-Mounted Motors? Herbert Chase.
Product Engng., Feb., 1930; v. 1, pp. 84-87.

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Application of Electric Drives to Rolling Mills in 1929. J. D. Wright.
Iron & St. Engr., Jan., 1930; v. 7, pp. 23-26.

Galvanometers

Sensitivity of a Galvanometer as a Function of its Resistance. H. B. Brooks.
Bur. Stds. Jour. Res., Feb., 1930; v. 4, pp. 297-312 (RP No. 150).

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Heat Transmission Problems and Some Recent Developments With Experimental Data. George E. Tansley and Otto Kubalek.
Inst. Engrs. & Shipbuilders Trans., Jan., 1930; v. 73, pp. 109-165.

Ionization

Variation of the Residual Ionization With Pressure at Different Altitudes, and Its Relation to the Cosmic Radiation. W. F. G. Swann.
Franklin Inst. Jour., Feb., 1930; v. 209, pp. 151-200.

Luminescence

Photoluminescence. Lyman Chalkley, Jr.
Illum. Engng. Soc. Trans., Feb., 1930; v. 25, pp. 172-183.

Measuring Instruments

Precision Industrial Recorders and Controllers. I. Melville Stein.
Franklin Inst. Jour., Feb., 1930; v. 209, pp. 201-228.
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Noises, Machinery

Analysis and Measurement of the Noise Emitted by Machinery. B. A. G. Churcher and A. J. King.
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(Bibliography of 41 entries, pp. 124-125.)

Radio Broadcasting

Wire Line Systems for National Broadcasting. A. B. Clark.
Bell System Tech. Jour., Jan., 1930; v. 9, pp. 141-149.
(A paper presented before the World Engineering Congress, Tokyo, Japan.)

Television

Television in Colors by a Beam Scanning Method. Herbert E. Ives and A. L. Johnsrud.
Optical Soc. of Am. Jour., Jan., 1930; v. 20, pp. 11-22.

Welding

Welding Developments in 1929.
Am Weld. Soc. Jour., Jan., 1930; v. 9, pp. 41-62.
(Illustrated summary of various kinds of electric, gas and thermit welding.)

NEW BOOKS

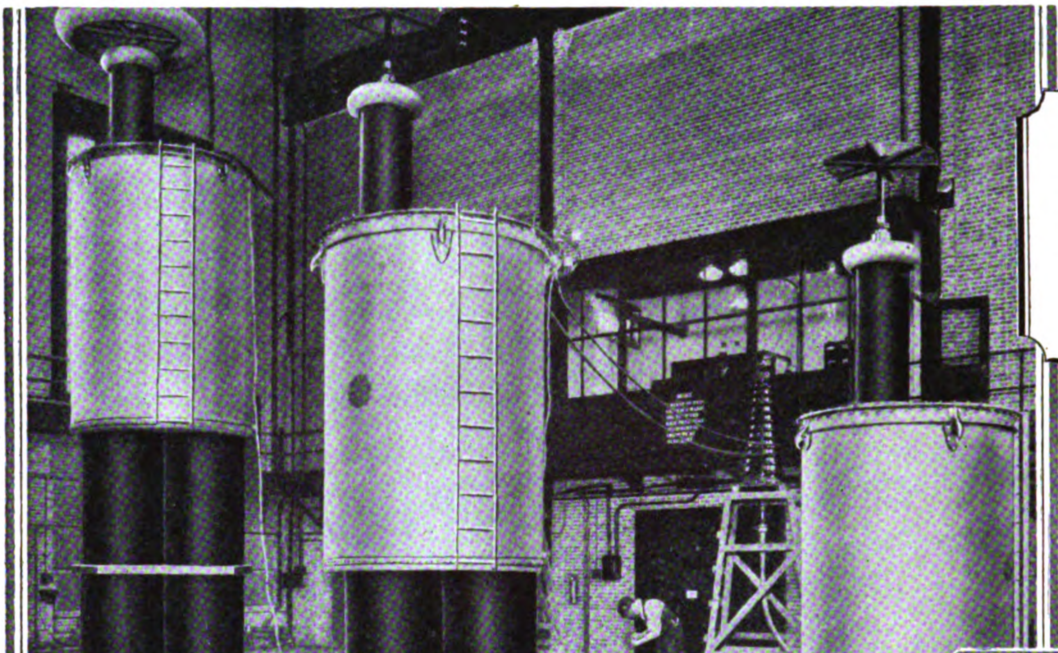
(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.)

Design of Electrical Apparatus. John H. Kuhlmann. 455 pp., N. Y., John Wiley & Sons, Inc. $6.00.
("The object of this book is to present a practical method of design in a clear and simple form with explanations of the theory, procedure, and limits of design. The procedure and methods employed are those used by the professional designer. The method of treatment adopted for each type of apparatus discussed is, first, to explain the construction of the apparatus to be designed; second, to explain the formulas and procedure; third, to give the design limits established by practice; and fourth, to illustrate with complete sample calculations. The complete design calculations are given for two direct-current machines, two synchronous machines, two induction motors, and four transformers... The design sheets used in the text are similar to those used by the commercial designer, and contain the predetermined characteristics and all the data necessary to construct the apparatus.")

Fundamentals of Radio. R. R. Ramsey. 372 pp., 1929, Bloomington, Ind., Ramsey Pub. Co. $3.50.
(The nature of this "elementary text-book for college students" is perhaps well expressed in the Preface, where the author says: "In the Fundamentals of Radio, I have endeavored to give the basic theory of radio as it is exemplified in modern practice. Perhaps if the fundamentals were limited in number to two they might be given as the resonant, or wave meter circuit, and the three electrode vacuum tube. This book will be found to be largely based on these two conceptions. An elementary knowledge of electricity such as is usually given in a first course in Physics is assumed. Although I have endeavored to give a non-mathematical treatment of the subject, some calculus has been introduced in a few sections. These mathematical sections have been developed and explained in a way which I hope will be helpful to the non-mathematical reader. The text has been illustrated by a large number of diagrams and pictures of radio apparatus. It has not been my purpose to illustrate all the modern circuits and 'hook ups.' A few typical circuits are given to show how the fundamentals are applied in modern practice.")

Operational Circuit Analysis. Vannevar Bush. 392 pp., 1929, N. Y., John Wiley & Sons, Inc.
(Although there is considerable literature on operational mathematics, in which the Heaviside methods are employed, there has been needed a text summarizing these various operations for the use of engineers and physicists. This, the author says, is the aim of the present volume. "The object of this text,' he says, "is an exposition and substantiation of operational methods in a form applicable to all sorts of circuit problems. Illustrations are given freely and these are often electrical; but this is not a collection of interesting electrical problems, nor a treatment of transmission lines and cables. . . . . I have attempted to include all the essential features of the Heaviside type of operational analysis, and to show their dependence upon the classic processes which constitute their background." The volume has resulted from studies made by Professor Bush while presenting the subject to graduate students of electrical engineering at the Massachusetts Institute of Technology. Professor Norbert, of the Department of Mathematics of the same institution, has provided an appendix of Fourier analysis and asymptotic series.)

Chain-connected



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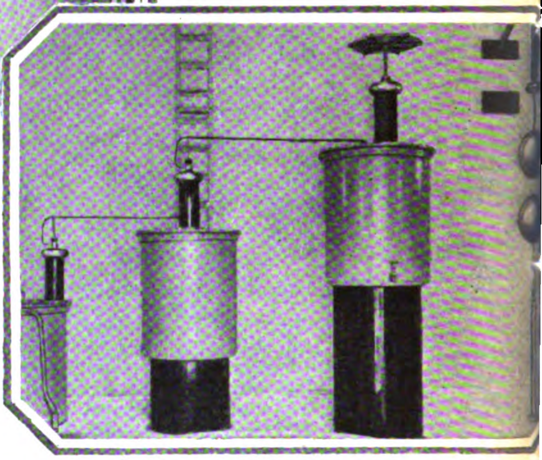
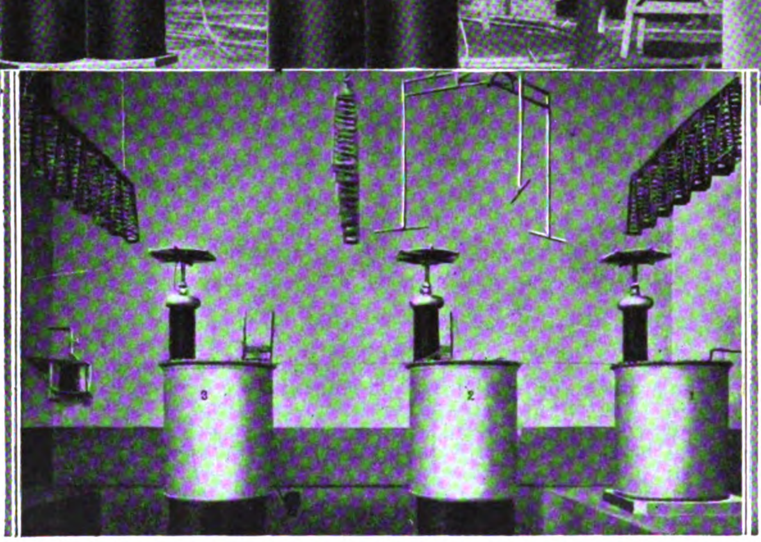
150,000-volt chain-connected transformers. Can be connected for 450,000 volts to ground or 260,000 volts, three-phase. Pacific Electric Manufacturing Corporation





250,000-volt chain-connected transformers. Can be connected for 750,000 volts to ground or 433,000 volts, three-phase. Simplex Wire and Cable Company

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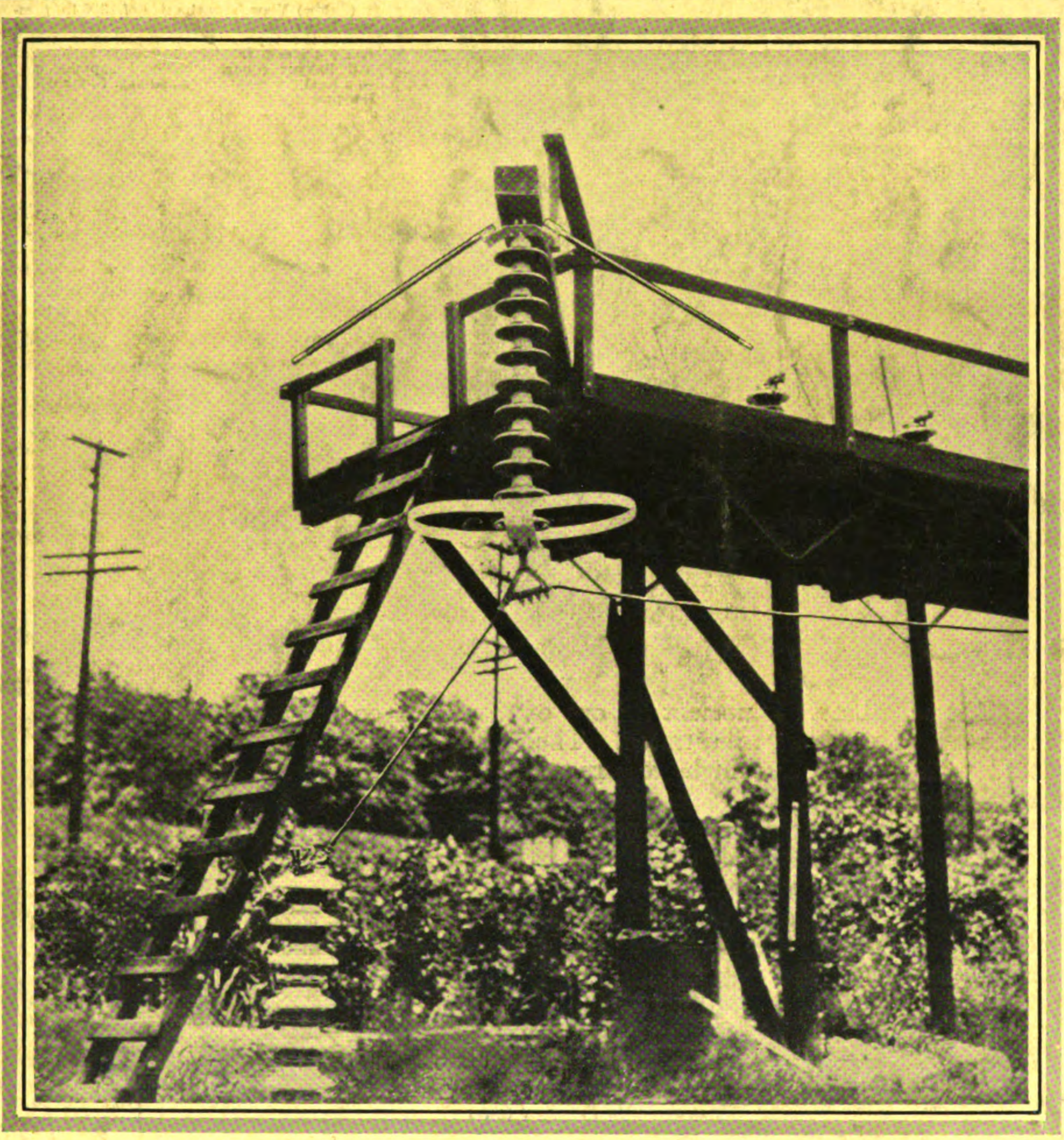
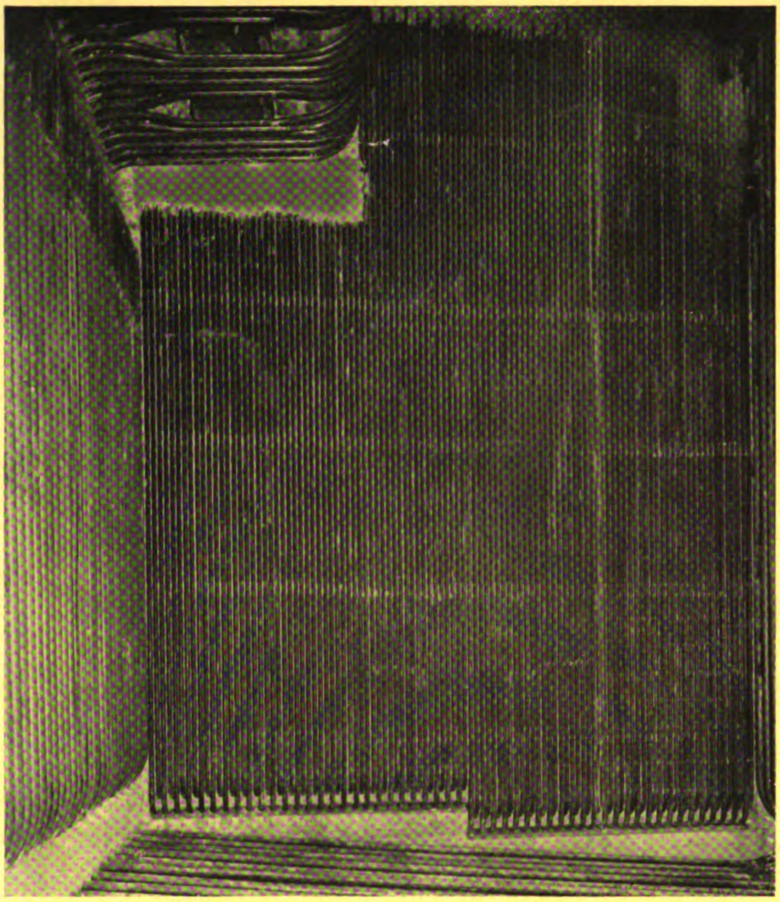


TO PREVENT AN ARC-OVER CAUSING AN OUTAGE

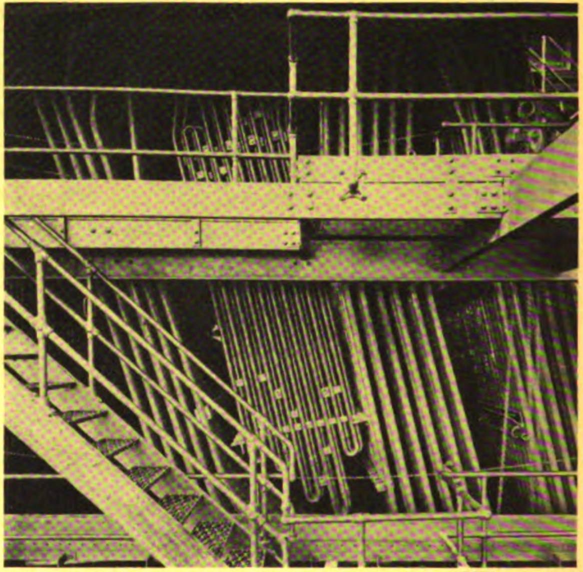
A test set-up of expulsion-type fuses in combination with a string of insulators and grading shield to determine the interrupting capacity of fuses in this application. (*See p. 336*)

In This Issue: *Springs versus Weights* — *Performance of Thyrite Arresters* — *The Power House for a Rayon Manufacturing Plant* — *Fused Grading Shield Tests* — *A Survey of Modern Physics* — *Characteristics of New General Electric Sunlamp*



Side wall of 2850-hp. furnace, consisting of a Foster Wheeler radiant heat superheater panel 22 ft. wide by 29 ft. high. It superheats half of the steam generated to a final temperature of 750 deg. F.

(Below) View from the side of 1390-lb. pressure boiler. In the center is the Foster Wheeler convection type steam re-superheater, which receives steam from high-pressure turbine at 310 lb. per square inch, and superheats it to a final temperature of 790 deg. F. for use in low-pressure turbines.



1390 Pound Pressure

The superheater equipment for one of the four 1390-lb. pressure boilers in the same plant is here illustrated. The boilers are each 2850 hp. and are fitted with radiant heat high-pressure superheaters and convection type re-superheaters.

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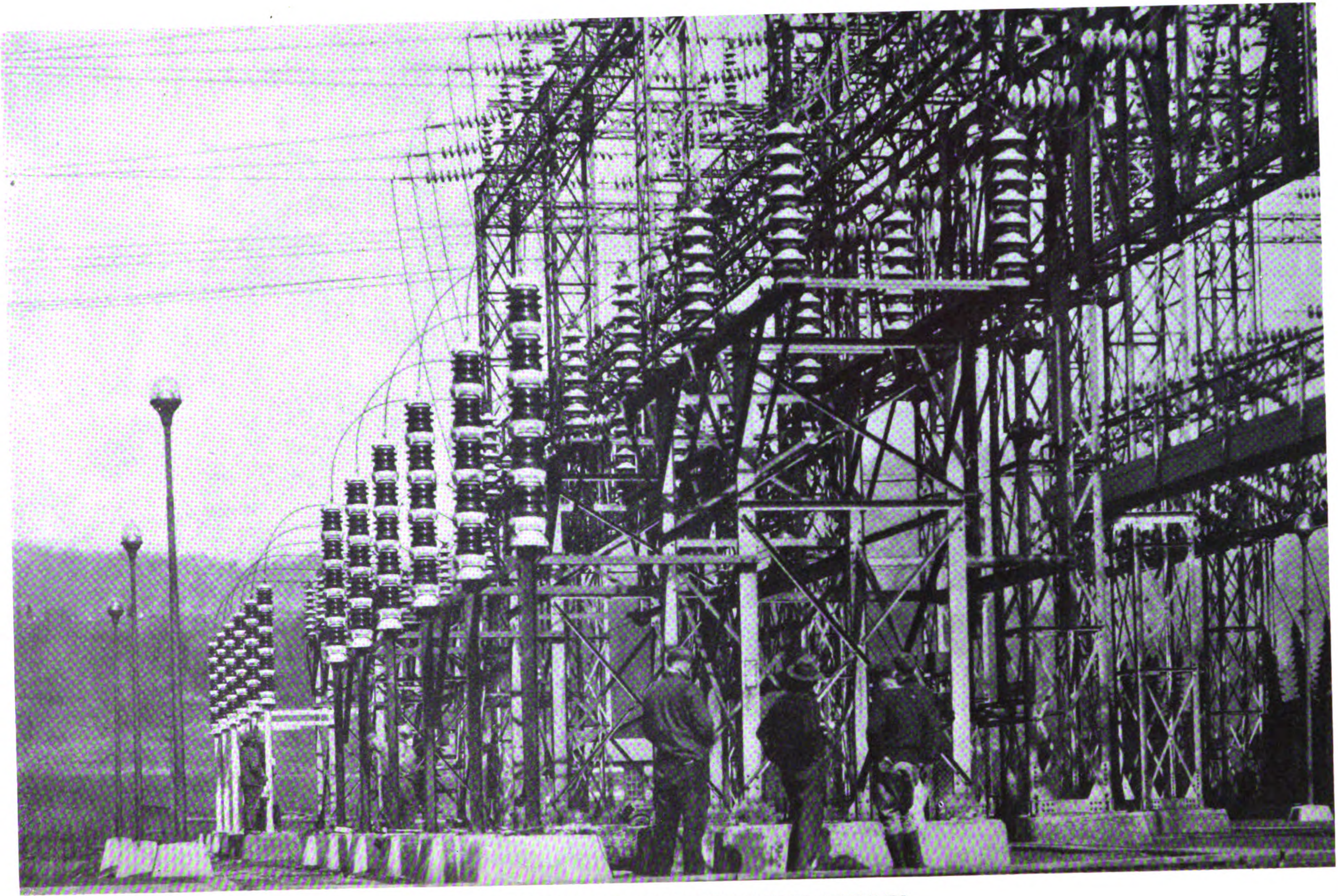

AN INSTALLATION OF STATION TYPE THYRITE ARRESTERS

GENERAL ELECTRIC REVIEW

Vol. 33 **June, 1930** **No. 6**

PHYSICS BROUGHT UP TO DATE

In leafing through this issue, we recognize the possibility that many who are engaged in purely engineering work might pass by the article on Modern Physics in the belief that it is too academic to be of much concern to them. To do so would be missing today's opportunity to become better acquainted with one of the valuable sets of tools destined for use tomorrow. On account of his familiarity with the subject, and the thought he has given to its possibilities, we have persuaded Dr. Dushman to supplement his theme with the following explanation of its significance.

* * * * *

To the engineer, the very foundation of his profession is based upon the laws of mechanics as formulated by Newton and developed by subsequent mathematicians. These laws have proved valid not only in the realm of industrial arts but also in that of astronomical observations, and have become part of our intellectual ensemble in dealing with the phenomena around us. It was natural to conclude therefore that the same conceptions also apply to atomic phenomena; and attempts were made to formulate mechanical models of atoms that would represent the actual observations on the behavior of atoms and electrons. In spite of a certain measure of success, as evidenced in the original Bohr theory, inconsistencies developed to a greater and greater extent with further investigation, until finally it came to be realized that a radical revision of the so-called classical conceptions was essential in order to obtain a more logical theory of atomic and electronic phenomena. It was then recognized that the main reason for the failure of Newtonian mechanics as applied to such phenomena is the fact that in the interaction of *matter* and *radiation*, the latter acts as if it were constituted of infinitesimally small energy units known as quanta, light darts, or photons. In other words, radiant energy is characterized by undulatory properties on the one hand (frequency and wavelength) and corpuscular properties on the other (definite units of energy and momentum).

Now it is of tremendous significance that in the most recent developments in physics it has been found necessary to attribute a similar dualism to the nature of *matter*. Matter is ordinarily conceived of as corpuscular; but in certain phenomena, discovered only within the past three years, matter behaves as if it were constituted of waves. Thus there is associated with corpuscles in motion a "wavelength," the magnitude of which varies inversely as the momentum. This is de Broglie's famous theoretical deduction, so signally confirmed by experiments on reflection of electron beams. It is upon this fundamental relationship that there has been developed a new conception, known as "Quantum Mechanics," which has been found to yield results in excellent quantitative agreement with observations when applied to atomic and electronic behavior.

It is a feature of this new mechanics that in the case of atoms, electrons, or similar corpuscles it enables us to predict only the *probabilities* of certain occurrences. That this type of mechanics merges into the ordinary mechanics for large-scale phenomena is due to the fact that in the latter case we are dealing with practically infinite numbers of atoms and hence a prediction can be made with certainty. Similarly, for a large group of human beings the life insurance actuarial tables can predict a definite number of deaths during any given period, but obviously when applied to any individual this prediction merely determines a probability for the occurrence of the event.

The reader may now ask: "What is the *practical* value of this new mechanics"? "Can its influence be evaluated in terms of dollars and dividends"?

Who can predict the ultimate value of any new idea? Has not the very history of human progress indicated the value of new ideas? When Clerk Maxwell put forward that famous equation

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}=\frac{\mu K}{c^2}\,\frac{\partial^2\phi}{\partial t^2}$$

for the propagation of electromagnetic energy, who could foretell that within the period of a single generation there would develop from this theory not only one of the greatest industries of the present day, but one which bids fair to become the greatest in the future?

Within the last four or five years, the new quantum mechanics has yielded answers to a number of questions that perplexed us previously, and has moreover predicted results which, on the basis of ordinary mechanics, would have seemed inconceivable, but which nevertheless have been found valid by actual test. We therefore perceive in these advanced conceptions a new key by which further chambers may be unlocked in that immense storehouse we call "Nature."

In the light of past experience, we must believe that as a result of this new physics not only shall the world be made a still better place in which to live, but also that it shall be possible to return unto Mammon that which is his due for his willingness to tolerate in his domains those idealists whose sole pleasure in life is the creating of advanced ideas. S. DUSHMAN

Modern Physics—A Survey

PART I

By DR. SAUL DUSHMAN
Assistant Director, Research Laboratory, General Electric Company

Introduction

IN order to appreciate the developments in physics which have occurred during the past twenty-five years, it is well to consider briefly the achievements in this science at the end of the nineteenth century.(1)

The first branch of physics to evolve as a well defined unit was mechanics. The genius of Newton gave it a form which could be developed to even greater perfection by succeeding mathematicians. Thus Lagrange was able to replace Newton's laws by a rather simple differential equation, and finally Hamilton demonstrated that all the laws of dynamics could be deduced from a single principle, the Principle of Least Action, which he expressed in a very elegant mathematical form.

The same methods were now applied to other branches of physics, such as acoustics, hydrodynamics and optics. In the latter branch, especially, Newton developed the corpuscular theory of light because of the obvious similarity between the laws of geometrical optics and the motion of material particles; while Fermat, in enunciating his principle of least time for the path of a light ray, stated a generalization which is the analogue of Hamilton's Principle of Least Action.

It is true that Huyghens favored a wave theory of light propagation, but it was only at the beginning of the nineteenth century that Young's experiments on interference led to the definite overthrow of Newton's theory by Fresnel and others.

The last century saw the birth and growth to full stature of the science of electricity with which the names of Volta, Ampere, Faraday, and Maxwell are connected. By the electro magnetic theory of Maxwell, optics and electricity became united as the science of waves *par excellence*, and the experimental proof of this point of view by Hertz was all that was needed, apparently, to confirm the whole theory.

It seemed as if the growth of physical science had been completed, and that no new epoch-making discoveries would be made. Yet the very last decade of the century saw the discovery of x-rays by Roentgen, of radioactivity by Mme. Curie, Rutherford, Soddy and others, and the conception of the electron theory by J. J. Thomson.

Still these new phenomena and the electron theory could have been comprehended in terms of the classical point of view, but other observations were made at about the same time, which could not be reconciled with any existing theory. In 1900 Lord Kelvin announced that there were apparently two clouds upon the physical horizon. One of these was represented by the experiment of Michelson and Morley, the other involved the failure of classical methods in accounting for the observations on the energy distribution in black-body radiation. As we know now, the first difficulty led to Einstein's Theory of Relativity, while the latter led to Planck's Theory of Quanta.

In the present connection we shall omit any further discussion of the theory of relativity except to point out its profound philosophical significance inasmuch as it puts time and space on an equal basis. They are merely two different attributes. Time is simply a fourth coördinate by which to describe the "world path" of a particle. The conception of absolute motion disappears, and, what is of even greater importance, the old respectable Principle of Causality is discarded, since, according to Einstein's theory, phenomena which are simultaneous for one observer need not be simultaneous for another observer moving with different velocity. We shall be compelled to return to this point once more in a subsequent section.

Origin of the Quantum Theory

Turning now to the theory of energy quanta, we find its inception, as mentioned already, in the observations on black-body radiation. These observations led to the conclusion that not only is matter atomic in its nature, but that radiant energy is emitted or absorbed in units, or quanta, whose magnitude is given by the expression $h\nu$, where ν is the frequency of the radiation and h is a universal constant. The postulation of such a theory meant a complete departure from the highly developed classical concepts. While the latter could always be formulated by differential equations denoting continuity, such a formulation could not be adapted to correlate the observations on black-body radiation, and subsequent discoveries have served only to emphasize the radical difference between the microphysical phenomena to which the quantum theory applies, and the macrophysical, which classical theory "explained" so well.

I have used the word "explained" in quotation marks because it is necessary, before proceeding further, to point out, as was first done by Mach(2), that theories in physics are not "explanations" of observed phenomena in the philosophical or metaphysical sense of the world. "In other words, theories contain no implicit conclusions regarding some reality *behind* the phenomena. Rather, the object of a physical theory is to develop *a system of conceptions which will enable us to describe the results of an experience*—a system which shall be as complete as possible and at the same time extremely simple and comprehensive."

---

(1) The following paragraphs are based largely on the remarks made by L. de Broglie in the introduction to his famous paper entitled "Researches on the Theory of Quanta," *Annales de Physique* 3, 22-128 (1925).

(2) This point is well brought out in a recent address by P. Jordan, *Naturwiss.* 16, 765 (1928).

Corpuscular Theory of Light

While Planck put forward his quantum hypothesis as a sort of tentative explanation of certain observed phenomena, it remained for Einstein (1905) to suggest a form of quantum theory which emphasized still more the discontinuous nature of energy. Taking as a fundamental axiom that energy is radiated in the form of light corpuscles or quanta of magnitude, $h\nu$, Einstein concluded that in the photoelectric effect the energy represented by this amount must be completely transferred to the electron which is emitted by the action of the light. If W denotes the work required to get the electron through the surface, and V, the maximum kinetic energy (in volts) of the emitted electron, then according to Einstein

$$h\nu = V\epsilon + W$$

where ϵ is the charge on the electron.

That is, the kinetic energy of the electron emitted by photoelectric action should be proportional to the frequency and not to the intensity of the incident radiation.

The confirmation of this relation mainly by Millikan (3) and the further observation that the same relation is valid for the inverse photoelectric effect (production of x-rays by electrons incident on a metallic surface) served to strengthen the validity of Einstein's "light-dart" theory. Thus appeared the first sign of dualism in theoretical physics. On the one hand, when measuring wavelengths of radiation we use the wave theory, but on the other hand, when we consider the interaction of radiation and matter, we find it more convenient to regard radiant energy as a sort of corpuscular entity, constituted of quanta, "light darts" or *photons*, travelling in straight lines and obeying the laws of geometrical optics.

Classical Theory of Radiation

Now according to the wave theory the simplest mechanism for the production of light is an electrical oscillator, that is, an electrically charged particle oscillating about a mean position of equilibrium with a restoring force which varies with the displacement according to some given law. If the restoring force varies directly as the distance, the displacements can be represented on a time axis as a sinusoidal wave of definite frequency, and according to classical electromagnetic theory, such an oscillator will emit monochromatic radiation of the *same* frequency as that of the oscillator; the latter is said to be of the linear *harmonic* type. However, *if the restoring force is not directly proportional to the displacement, but varies according to some higher power of the latter*, then the oscillator is spoken of as the *anharmonic* type. The displacement, as a function of the time, is then represented by a combination of a sine or cosine wave of the same frequency as in the harmonic type (fundamental frequency) and other sine or cosine waves whose frequencies are integral multiples of the fundamental. The radiation is then no longer monochromatic, but consists of a whole range of frequencies which may be represented by a *series* of values, such as ν, 2ν, 3ν, etc., the whole constituting a range of frequencies which resembles from a formal standpoint the fundamental note and overtones which are emitted by a vibrating string in acoustics. Mathematically the motion of such an oscillator and the resulting intensity of the electromagnetic radiation as a function of the time, may be represented by a Fourier series in which each *harmonic* of the fundamental frequency is represented by the product of a constant (which gives the maximum amplitude of the corresponding radiation) and a cosine or sine function of the particular frequency.

Bohr Theory of Energy Levels

This picture of the origin of radiation, based on the so-called classical theory of electrodynamics, is of particular interest because it was found to lead to conclusions which are in distinct and irreconcilable contradiction with the actual observations on the frequencies of spectral lines emitted by the various elements.

For it had been observed that the lines in the spectrum of an element, such as sodium, could be arranged into a few series in each of which the frequencies of the lines are connected by a rather unexpected, but simple relation of the form $\nu = A - B/m^2$, where A and B are constants for any given series, and m *assumes successive integral values for different members of the same series*. In other words, while classical theory led to the expectation that the frequencies of lines would be found to be harmonics of one, or at most a few fundamental frequencies, the spectroscopists found that each line in the spectrum could be represented as a *difference between two terms*. Such an observation obviously cannot be made in general to conform with the representation of the lines by a Fourier series, and hence the mechanism of production of spectral lines cannot be any linear oscillator of the type demanded by classical theory.

It was, however, this very observation that spectral lines may be represented as differences between two terms which was used as the most important fact for formulating a completely new theory of the origin of spectral lines. For this purpose, Bohr also incorporated the conclusions reached just previously by Rutherford, Geiger, and Marsden that the atom must be regarded as constituted of a positively charged nucleus and one or more electrons, the number of electrons being equal to the number of positive units of electricity on the nucleus and each equal to the atomic number, N, which represents the place of the element in the periodic arrangement.

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(3) For an account of this work, see R. A. Millikan: "The Electron," Chicago University, 1917.

In such an atomic system the attraction of the electrons by the positive nucleus may be balanced in one of two ways: either we can assume stationary electrons and a force of repulsion which just balances the force of attraction when the electrons are at certain distances from the nucleus, or we can assume that, as in the solar system, the force of attraction is balanced by the centrifugal force due to rotation of the electrons in orbits. For many reasons Bohr took the latter view, since the problem could then be treated in the same manner as Newton had originally dealt with the analogous problem in celestial mechanics. On this point of view, the model of the hydrogen atom is that of a single electron rotating about a unit positive charge in an elliptic orbit of definite major axis.

This is the normal hydrogen atom; but in order to account for the observations on line spectra, Bohr found it necessary to introduce two postulates: firstly, that any atomic system is capable of existing in a series of discrete *stationary* states, for each of which the energy is different; and secondly, that *monochromatic radiation is emitted or absorbed whenever the system passes from one state to another*, the frequency of the radiation being given by a relation of the form

$$\nu = E_i/h - E_f/h$$

where E_i and E_f represent the energies in the initial and final states respectively. It will be recognized that this equation for ν is of the same form as that observed by spectroscopists and that according to Bohr the spectral terms A and B/m^2 are to be interpreted as *energy levels*. In other words, he assumed that these levels or stationary states corresponded, in the case, say, of the hydrogen atom, to different orbits in which the electron may rotate and that the laws governing these orbits are those of ordinary mechanics. Furthermore, in order to define these orbits, Bohr introduced a certain quantum condition, which in the case of a circular orbit may be stated in the form that the angular momentum of the electron in its orbit must always be an integral multiple, n, of the mystic constant, $h/(2\pi)$. The different stationary states thus correspond to different orbits for which the radius increases as n^2 where n is known as the quantum number, while the frequency of rotation decreases with increase in radius.

Of course, according to classical theory, an electron rotating in orbit must radiate energy continuously, which would lead to a continuous decrease in the radius with corresponding increase in frequency of rotation, until finally the electron would fall into the nucleus. But Bohr merely denies the occurrence of such a phenomenon for electronic orbits, and postulates, as mentioned already, that emission (or the inverse process, absorption) of radiation occurs *only during a transition* of the electron from one orbit to another.

The only defense to be offered for such a set of postulates and assumptions was that they led to remarkable results. Bohr showed that not only could this theory give quantitatively the lines observed in the hydrogen spectrum, but by suitable modification it could be made to account qualitatively for the different series spectra observed for a large number of other elements. As a logical deduction from Bohr's frequency relation it follows that if we have three energy levels, say E_1, E_2, E_3 where

$$\nu_{1,2} = (E_1 - E_2)/h \text{ and } \nu_{2,3} = (E_2 - E_3)/h$$

then it should be observed that

$$\nu_{1,3} = \nu_{1,2} + \nu_{2,3} = (E_1 - E_3)/h$$

The validity of this law, known as the Ritz Combination Principle, had also been observed empirically by spectroscopists, but Bohr first pointed out its significance as a consequence of his theory of energy levels.

The extension of Bohr's ideas by Sommerfeld and others led to a fairly consistent picture of atomic structures in which the more complex atoms could be regarded as being built up from elements of lower atomic number, N, by successive addition of electrons rotating in various elliptical and circular orbits. Also the experiments initiated by Franck and Hertz and continued by a number of American investigators, on the excitation and ionization of atoms by collisions with electrons, and the correlation of the results with certain lines in the spectra of these atoms—all these observations coming as direct consequences of Bohr's theory of energy levels—seemed to serve as a proof of the actual existence of electronic orbits.

Atomic Mechanics on Classical Basis

However, when it came to the application of the laws of Newtonian mechanics to atomic systems containing more than one electron, difficulties began to be encountered of a more and more serious nature. For one thing, ordinary mechanics deals with continuously varying systems and the existence of discrete energy states with quantum transitions presents a phenomenon totally foreign to the whole of classical theory. In the case of an electric oscillator, the frequencies of radiation emitted are simple multiples of a fundamental, and the intensities of the individual monochromatic radiations are proportional to the squares of the amplitudes of the corresponding displacements in the motion of the oscillator. But in atomic systems, the frequency of emission of radiation bears no such simple relation to the frequency of rotation of the electron in its orbit, nor, in general, can the intensity of the light emitted be measured by any properties of a single orbit, since the radiation originates in a transition between two orbits. Under such conditions how can one modify the laws of ordinary mechanics to obtain results in agreement with actual observations?

Bohr had recognized these difficulties early in the development of the theory, but had pointed out that under certain conditions the deductions obtained by classical theory for macroscopic systems must be valid for atomic systems as well. It is well known that the laws of classical electrodynamics apply to radiation of long wavelength: but such radiation is obtained, on the point of view of the new theory, by transitions between orbits of very large radius, where the frequency of rotation is much smaller than for orbits of smaller radius (smaller values of the quantum number, n). For such large orbits, the frequency of the radiation emitted in passing from one orbit to a neighboring one is approximately equal to a simple multiple of the frequency of rotation in either orbit, in accordance with classical theory. Hence the *laws of ordinary mechanics may be applied to orbits of large quantum number* and the deductions thus obtained may then be extrapolated to the case of orbits of small quantum number. This idea that, in the limit the laws of quantum mechanics must approach asymptotically those of ordinary mechanics, was formulated by Bohr as his famous *Correspondence Principle*, and still furnishes the background for even the most recent developments in quantum mechanics. It will be observed that the essential purpose of this principle is to retain in atomic mechanics as much as possible of that classical mechanics which found its most important formulation in the so-called Hamiltonian canonical conditions and the Hamilton-Jacobi partial differential equation.

Difficulties in Applying Classical Mechanics to Atoms

However, while this quantum mechanics, based, as it was, on a hybridization of ordinary mechanics and quantum discontinuities, gave quantitative results in the case of the normal hydrogen atom and ionized helium, it met with real difficulties in the treatment of the *spectrum of neutral helium*, where two electrons revolve around the nucleus. In the case of atoms of higher atomic number, the problem obviously becomes still more complex. Bohr attempted to deal with these atoms as perturbed states of the simple hydrogen-like system. By introducing the notion of penetrating and non-penetrating orbits a certain measure of success was obtained in deriving a general form of expression similar to that which had been found to apply to terms in the hydrogen spectrum. Also, by assigning to each electron in the atom *four different kinds of quantum numbers*, Sommerfeld, Landé, Pauli, Heisenberg, and others, were able to develop semi-empirical formulas for the separation of multiplets and for the effects of magnetic and electric fields on spectral lines. In order to account for the absence of certain classes of transitions between levels, it was also found necessary to postulate certain *Principles of Selection* regulating the nature of the possible transitions.

A further important generalization was derived by Pauli according to which: "There cannot exist in any one atom two electrons having the four quantum numbers respectively the same for both." Utilizing this rule and the different selection principles, Hund was able to deduce a correlation between the arrangement and nature of the electrons in any atom, on the one hand, and the spectroscopic normal term on the other. (4)

As stated already, all this development was based on more or less empirical considerations. All attempts to derive the same results by the methods of Newtonian or classical mechanics proved unsuccessful, and hence the question arose as to whether there is any reason whatever for expecting successful results by this method. Physicists like Bohr, Born, Heisenberg, and others, began to consider the whole problem from a more fundamental point of view. As stated by Born, (5) "After all, no other result could be expected, for the validity of the frequency condition is sufficient to show conclusively that in the realm of atomic processes the laws of classical theories (geometry, kinematics or mechanics, electrodynamics) are not right. That in certain simple cases, as for a single electron, they give partially correct results, is, in fact, more astonishing than that they fail in the more complicated cases of several electrons. This failure of the theory in the case of interactions among several electrons is evidently connected with the following fact. We know that *electrons react quite unclassically to light waves, because the latter produce quantum jumps*. In a system made up of several electrons, each electron is in the oscillating field due to all other electrons and the periods of these fields are of the same order of magnitude as those of light waves, therefore we have no reason to expect that the electron should react classically to this oscillating field. This point of view gives grounds for understanding why we obtain, by the classical theory, correct results in many cases of the one electron problem."

Failure of Principle of Causality

Also, it is of importance to realize the difficulties involved in the simple model of electronic transitions between levels. In passing, for instance, from a higher to a lower level, the atomic system radiates monochromatic energy. When does this radiation occur? If it occurs during the transition then the electron knows the ultimate level to which it shall pass. This obviously means a *doctrine of determinism* and is therefore utterly absurd. Bohr, Kramers, and Slater suggested in 1925 a theory which would permit the electron to radiate while in its orbit, without the occurrence of the transition, until a definite amount of energy had been emitted. On this point of view, the law of conservation of energy as applied to atomic system would assume the nature of a statistical principle, that is, one which is true on the average for a large number of transitions, but not necessarily valid for each individual transition. But more recent investigations, especially those connected with the Compton effect (see below) showed the untenability of this point of view. It was demonstrated that the transitions are governed by the existence of certain probabilities for their occurrence. *Hence it is no longer possible to assume a causal mechanism governing the transitions.*

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(4) For a detailed account of this work see the writer's paper on "Line Spectra and the Periodic Arrangement of the Elements," *Chemical Reviews 5*, 109-171 (1928).

(5) M. Born: "Problems of Atomic Dynamics": Lectures delivered at M.I.T. in 1926.

In fact, it was perceived that the failure to attain successful results by the application of Newtonian mechanics is in reality bound up with the *failure of the so-called Principle of Causality when applied to microphysical phenomena.* As will be shown in a subsequent section, this principle has been found to be just as unnecessary in the new quantum physics as the hypothesis of an ether in the theory of relativity.

Compton Effect

Mention has already been made of the difficulties encountered by physicists owing to the necessity of assuming two different hypotheses for the mechanism by which radiant energy is propagated. Waves or corpuscles? This was the most important question, and numerous attempts were made to settle it. In 1922–3, A. H. Compton discovered a new phenomenon which served to emphasize still more the corpuscular nature of radiation.

When an x-ray impinges on matter, a secondary x-ray is produced of slightly longer wavelength or lower frequency. This is contrary to what would be expected on the basis of classical theory. In order to explain this observation, Compton utilized the theory of light darts or photons, as we prefer to designate them now.

On this theory, the x-rays consist of streams of energy quanta. While each quantum carries the energy equivalent to $h\nu$, we may also specify each of these photons (light units) by the momentum, which, according to the theory of quanta, is equal to $h\nu/c$. When this photon collides with a free or loosely bound electron there is an interchange of both energy and momentum in accordance with the laws of conservation of energy and momentum. Consequently the photon suffers a recoil in one direction with loss of momentum, while the electron moves off in another direction with added momentum. The collision, is, indeed, analogous to that of a golf ball striking a perfectly elastic football. The decrease in momentum of the scattered x-ray photon corresponds to an increase in wavelength.

Compton found that the actually observed changes in wavelength were in agreement with the theoretical predictions based on the above assumption. A further point that was brought out by subsequent experiments is that this conservation of momentum and energy is not the result of a statistical state of affairs, but must hold valid for every individual collision between a photon and electron.

Here, then, we have a phenomenon which must be recognized as indicating almost conclusively the corpuscular nature of light energy. Yet in these very experiments Compton made use of the wave theory in measuring the wavelength of the secondary radiation!

New Quantum Mechanics

The solution of the difficulties which thus presented themselves to physicists until within the past four years has been approached from two directions which were believed at first to be quite different, but which have been shown on closer investigation to be merely different methods of expressing the same idea. As a preliminary to the consideration of these solutions we shall quote the following remarks from Born's lectures:

"In seeking a line of attack for the remodelling of the theory, it must be borne in mind that weak palliatives cannot overcome the staggering difficulties so far encountered, but that the change must reach its very foundations. It is necessary to search for a general principle, a philosophical idea, which has proved successful in other similar cases. We look back to the time before the advent of the theory of relativity, when the electrodynamics of moving bodies was in difficulties similar to those of the atomic theory of today. Then Einstein found a way out of the difficulty by noting that the existing theory operated with a conception which did not correspond to any observable phenomenon in the physical world, the conception of simultaneity. He showed that it is fundamentally impossible to establish the simultaneity of two events occurring in different localities, but rather that a new definition, prescribing a definite method of measurement is required. Einstein gave a method of measurement adapting itself to the structure of the laws of propagation of light and of electromagnetic phenomena in general. Its success justified the method and with it the initial principle involved: The *true laws of nature are relations between magnitudes which must be fundamentally observable.* If magnitudes lacking this property occur in our theories, it is a symptom of something defective. The development of the theory of relativity has shown the fertility of this idea, for the attempt to state the laws of nature in invariant form, independently of the system of coördinates, is nothing but the expression of the desire of avoiding magnitudes which are not observable. A similar situation exists in other branches of physics.

"In the case of atomic theory, we have certainly introduced, as fundamental constituents, magnitudes of very doubtful observability, as, for instance, the position, velocity, and period of the electron. What we really want to calculate by means of our theory and can be observed experimentally, are the energy levels and the emitted light frequencies derivable from them. The mean radius of the atom (atomic volume) is also an observable quantity which can be determined by the methods of the kinetic theory of gases or other analogous methods. On the other hand, no one has been able to give a method for the determination of the period of an electron in its orbit or even the position of the electron at a given instant. There seems to be no hope that this will ever become possible, for in order to determine lengths or times, measuring rods and clocks are required. The latter, however, consist themselves of atoms and therefore break down in the realm of atomic dimensions. It is necessary to see clearly the following points: All measurements of magnitudes of atomic order depend on indirect conclusions; but the latter carry weight only when their train of thought is consistent with itself and corresponds to a certain region of our experience. But this is precisely not the case for atomic structures such as we have considered so far.

"At this stage it appears justified to give up altogether the description of atoms by means of such quantities as 'coördinates of the electrons' at a given time, and instead utilize such magnitudes as are really observable. To the latter belong, besides the energy levels which are directly measurable by electron impacts and the frequencies which are derivable from them and which are also directly measurable, the intensity and the polarization of the emitted waves. We therefore take from now on the point of view that the elementary waves are the primary data for the description of atomic processes and all other quantities are to be derived from them."

The work which led directly to the formulation of the new quantum mechanics was that of Kramers and Heisenberg on dispersion of light. They found it possible to obtain relations in which the effects of incident radiation on an atom could be expressed in terms of frequencies and amplitudes of the spectral lines emitted by the atom. This then led Heisenberg to attempt the development of a new scheme of quantum mechanics in which, instead of using such conceptions as orbits, orbital frequencies, and similar magnitudes (which, by the very nature of things, can never be observed directly), actually observable energy levels and intensities of spectral lines could be correlated directly. For this purpose it was found necessary to apply a new kind of mathematics, the *matrix calculus*, which, although well known to mathematicians, was quite foreign to theoretical physicists. In the development of this matrix mechanics, Born, Jordan, and Pauli, along with Heisenberg, have played a prominent rôle.

The kind of mathematics used involves the use of complex quantities, or what Dirac has designated as "q-numbers," instead of ordinary, or "c-numbers." The ordinary variables p and q of classical mechanics, which correspond respectively to actual momentum and coördinate of position for a material particle, are replaced in the new calculus by quantities which can have no physical interpretation, and the following remarks are therefore to be regarded only as an attempt to give a crude picture of the mathematical reasoning.

According to classical mechanics, any frequency $\nu_{m,\,n}$ due to a transition from state m to state n can arise only from a harmonic oscillator executing oscillations of this frequency. Heisenberg therefore introduces the notion of a *virtual oscillator*, which by its motion would emit a frequency and amplitude corresponding to any given frequency and intensity observed in the spectrum of the atom. Since there are an infinite number of possible transitions between the different energy levels, it is necessary to consider an infinite array of such virtual oscillators. The frequencies of these oscillators are, however, all interconnected by the Ritz relation or Bohr frequency condition, which may be expressed in the form

$$\begin{aligned}\nu_{m,\,n} &= \frac{W_m - W_n}{h} \\ &= \frac{W_m - W_k}{h} + \frac{W_k - W_n}{h} \\ &= \nu_{m,\,k} + \nu_{k,\,n}\end{aligned}$$

where W_m, W_n, W_k are any three energy levels and $\nu_{m,\,n}$ $\nu_{m,\,k}$ $\nu_{k,\,n}$ denote frequencies of light emitted in transitions between these levels.

How can one deal mathematically with such an "orchestra" of oscillators? This is the question which Heisenberg asked himself. After he had derived rules of computation, it was recognized by Born that the method used by Heisenberg is essentially that previously devised by Cayley and other mathematicians for the solution of linear algebraic equations, and known as the calculus of matrices.

One of the most important features connected with this kind of algebra is the fact that the product $a \times b$ is no longer equal to $b \times a$. That is, multiplication is said to be *non-commutative*. In ordinary mathematics we meet with a similar condition of affairs when we consider the product of a number by an operator such as d/dx. For instance, $a \times (d/dx)\, b$ is usually different from $(d/dx)\,(ab)$ where a and b are functions of x. In consequence of this non-commutativity, the quantum condition assumes the incomprehensible form

$$qp-pq=\frac{h}{2\pi}\sqrt{-1}$$

where it must be remembered that p and q are no longer ordinary or c-numbers, but designate elements in the $p-$ and $q-$ matrices. Instead of single variables, p and q, such as are used in ordinary mechanics, we now have infinite arrays of $p-$ and $q-$ terms, each array constituting a matrix, in which we have rows and columns as in determinants. Thus whereas in classical theory the motion of a linear oscillator would be represented by a Fourier series for a single coördinate q, and the frequencies of radiation emitted would be exclusively different possible harmonics of one fundamental frequency—the corresponding calculation in matrix mechanics replaces the single coördinate by a two dimensional array of q's, each of these corresponding to a possible transition between two energy levels.

Now the rules of multiplication of matrices are such that they lead automatically to the Bohr frequency condition stated previously. Furthermore, by introducing the quantum condition given above for the p's and q's considered as matrix elements, and combining this condition with the proper Hamiltonian form of expression for the total energy as a function of the p's and q's, it is possible to obtain the correct expression for the different possible energy levels.

Thus the matrix mechanics is essentially a set of rules which enable us to calculate the correct energy levels and corresponding transition frequencies for any given atomic system. Heisenberg has shown that the method may be extended to systems such as those of helium and more complex atoms and gives, in each case, results in quantitive agreement with observation.

De Broglie's Phase Waves

Shortly after the publication of the first papers by Heisenberg and Born, Schroedinger also attacked the problem of atomic mechanics from another point of view which was inspired largely by certain speculations of de Broglie (6) on the association of wave motions with material particles.

To understand the considerations which influenced de Broglie towards postulating this suggestion, it is necessary to refer briefly to a relation, pointed out more than a century ago by Hamilton, between optics and dynamics. As mentioned already, the laws of dynamics may be expressed in their most general form by the principle of least action, according to which the path of a particle, or system of particles, from one given initial configuration to any other final configuration, the energy of the system remaining constant, is such that the *line integral of the momenta of all the particles is a minimum.* For a single particle this is stated mathematically in the form that

$$\int_o^s mv.\,ds=\text{minimum}$$

where v is the velocity of the particle at any point and s denotes the distance measured along the path.

In optics there exists an analogous relation governing the path of a ray of light through a medium for which the refractive index (and therefore the velocity of light) varies from point to point. This is known as Fermat's principle, and states that the path of the ray is such that the *time* taken for the light to pass from one given point to another must be a *minimum*, that is

$$\int_o^s \frac{ds}{u}=\text{minimum}$$

where u denotes the velocity of light at any point and s, the distance along the path of the ray.

Now the laws of geometrical optics are more and more valid the shorter the wavelength of light compared with the dimensions of the object upon which the light impinges. But where this is not the case, we find that these laws are no longer applicable, and in order to understand the diffraction phenomena observed under these conditions it is necessary to consider light as a wave motion. That is, Fermat's principle can no longer be applied. The analogy between this principle and that of least action suggested to de Broglie that perhaps the accepted mechanics of Newton (and the principle of least action itself) is also an approximation which is valid for macroscopic systems only because the wavelength is extremely small, but that for atomic systems this is no longer true, and therefore ordinary mechanics fails when applied to such cases.

In order to complete the parallelism between the principle of Fermat and that of Hamilton it is therefore necessary to assume that *along with the corpuscular motion of velocity v*, there *is associated a wave motion of velocity u which is inversely proportional to v, i.e.,*

$$u\sim\frac{1}{mv}$$

Such a relation is actually found to exist between the phase velocity, u, of the individual waves and the group velocity, v, of a group of waves formed by the superposition of a large number of waves of slightly different wavelengths. The classical illustration of such a wave-group is that formed in deep water by a series of individual waves of different wavelengths. At certain points these waves add their amplitudes to produce a crest and at other points the individual waves interfere to form a hollow, and it is found that in general the velocity of the crest (group-velocity) is different from that of the separate wavelets (phase velocity).

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(6) loc. cit.

De Broglie was led by these considerations to the conception, that associated with a particle of mass m_o (the mass at zero velocity or "rest mass") and velocity v, there is a wave motion for which the wavelength is given by

$$\lambda = \frac{h\sqrt{1-v^2/c^2}}{m_o v} = \frac{h}{m_o v}$$

for small values of v, where c = velocity of light.

According to the theory of relativity, the total energy, E, of any particle of mass m_o is given by

$$E = \frac{m_o c^2}{\sqrt{1-v^2/c^2}} = mc^2$$

where m is the mass for velocity v. Now according to the quantum theory, the frequency associated with a quantity of energy, E, is given by E/h. Hence the phase velocity or velocity of the individual waves constituting the group is given by

$$u = \nu\lambda = \frac{mc^2}{mv} = \frac{c^2}{v}$$

The analogy between Fermat's principle and that of Hamilton is thus made formally complete. Before discussing the interpretation of this analogy, let us consider what values we can expect on the basis of de Broglie's theory, for certain typical cases of corpuscular motion. The value of h as determined by different methods is 6.55×10^{-27} erg-sec. Hence for a mass of 1 gm. moving with a velocity of 1 cm. per sec., the associated wavelength is 6.55×10^{-27} cm. This is certainly a value much too small to be measured by any sort of grating available. From the study of x-rays we know that it is possible by means of crystal lattices to measure wavelengths ranging from 10^{-10} to 10^{-7} cm., while optically ruled gratings enable us to measure wavelengths exceeding 10^{-6} cm. Thus if de Broglie's assumption is valid, we would expect to find that corpuscular motion will exhibit phenomena of the same nature as those previously associated with light waves, under those conditions where the momenta of the particles are of the order of magnitude $mv = h/10^{-10}$ to $mv = h/10^{-7}$, *i.e.*, for values of mv ranging from 6.55×10^{-17} to 6.55×10^{-20}. The magnitude of these values shows that we can expect such phenomena only in the case of atoms or electrons. Thus according to the kinetic theory of gases, a hydrogen molecule ($m = 3.7\times10^{-24}$) has a velocity of about 2×10^5 cm. sec.$^{-1}$ at room temperature. The value of mv is therefore 6.6×10^{-19} which is within the range mentioned above. An electron falling through a potential of 100 volts acquires a velocity of 5.9×10^8 cm. sec.$^{-1}$. Multiplying this by the mass ($m = 9\times10^{-28}$), we obtain the result $mv = 5.3\times10^{-19}$, and $\lambda = 1.24\times10^{-8}$ cm. For cathode rays of 25,000-volt velocity, λ calculated in the same manner is 0.75×10^{-9} cm. approximately.

Thus we might expect to find in the case of atoms and electrons certain phenomena exhibiting the characteristics ordinarily associated with waves, and incidentally this would be an argument for de Broglie's postulate that for such particles it is no longer justifiable to expect exact results by application of Newtonian mechanics.

Diffraction of Electrons

Now as has happened in the history of science many times, the observations confirming this view became available very shortly after the publication of the work of de Broglie and Schroedinger.

This experimental evidence of the wave nature of matter was obtained by two physicists, C. J. Davisson and L. H. Germer, in the Bell Telephone Laboratories. They observed that electrons of moderate velocities (20 to 200 volts) impinging on a single crystal of nickel are reflected more frequently in certain favored directions, depending upon the velocity of the electrons and upon the distance between the atomic layers, in the crystal lattice, which happen to be normal to the plane containing both the incident and reflected electron beams. Applying the same relations as had been used by Bragg to determine the wavelengths of x-rays diffracted by a crystal lattice, *Davisson and Germer found for the diffracted electrons values of λ in accordance with de Broglie's relation.*

Furthermore, in England, G. P. Thomson actually sent high velocity electrons (15,000 to 30,000 volts) through thin metal foils and obtained on a photographic film diffraction patterns of exactly the same appearance as those obtained by Laue in his classical demonstration of the wave-nature of x-rays. G. P. Thomson merely applied the formula which had been used for x-rays, to the diffraction of electron beams by the metal foil and obtained values of λ which were, again, in exact agreement with de Broglie's relation.

It is indeed a dramatic feature of recent developments in physics that the very same methods which had been used to demonstrate, without a shadow of a doubt, the undulatory nature of x-rays (which, in the Compton effect, inverse photo-electric effect and ionization effect exhibit corpuscular phenomena) —that these same methods should have been used for the same purpose in connection with rays (electron beams) which had hitherto been considered as *prima facie* corpuscular. For what could be more justly regarded as a corpuscle than the infinitesimal electron whose charge and mass had been determined by J. J. Thomson by recognized electro-dynamical laws?

More recently evidence has been obtained that beams of atoms of hydrogen and other gases reflected from crystal surfaces also exhibit phenomena which may be interpreted from the undulatory point of view. But these observations are not yet so conclusive as those obtained in the case of electrons diffracted by crystals.

(*To be continued*)

Fused Grading Shield Tests

On System of Alabama Power Company—Assembly of Conductor, Insulators, Grading Shield, and Fuse—Method of Test—Data on Rupturing Capacity and Performance of Fuses—Suitable Applications

By **J. E. CLEM**

Central Station Engineering Department, General Electric Company

DURING the summer of 1927 the Union Gas and Electric Company(1) made tests on a fuse device designed to prevent a line flashover from resulting in an outage. The device originally consisted of the ordinary grading ring and arcing horn assembly modified by the addition of two insulator units below the ring, which units were short-circuited by a high-voltage fuse of the carbon-tetrachloride type. The device was successful and with the later adoption of the double-ended expulsion-type fuse interest in it has grown considerably. Its use was initially handicapped by lack of information as to the ultimate rupturing capacity of the fuses when used in this manner. This article is presented to give briefly the results of some tests made on a 110-kv. circuit to observe the rupturing capacity and performance of fuses when used in the fused grading shield assembly. These tests were made possible through the coöperation of the Alabama Power Company and the Locke Insulator Corporation.

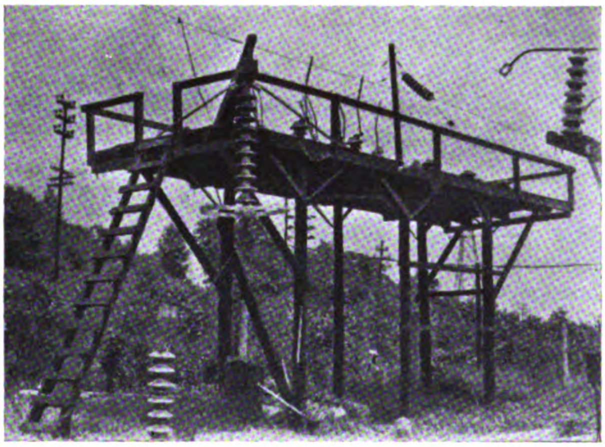

Fig. 1. General View of the Set-up Constructed for Making the Fused Grading Shield Tests on the System of the Alabama Power Company

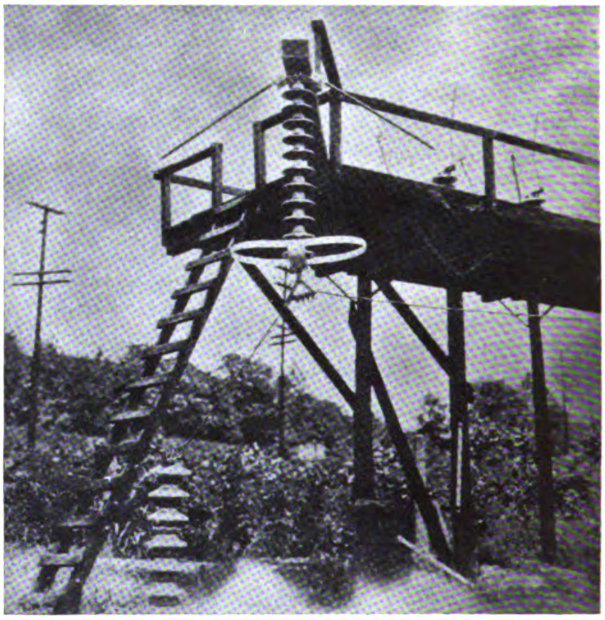

Fig. 2. Close-up View of the Test Assembly. The two expulsion fuses are shown sloping downward to the left and right above the grading shield

The fuses tested were standard General Electric expulsion-type fuses (Cat. 2878686G47). This type of fuse consists of a fibre tube with a metal ferrule at each end. The tube encloses the fuse element, which is a very short metal link. The link is connected in series with a flexible copper cable which is held in tension by a compressed spring. The tube is closed at each end, the closure at the lower end being a target to indicate operation. One or both ends of the fuse blows out depending upon the magnitude of the current interrupted. For these tests a 73-kv. fuse was used with a 5-amp. element. This fuse has a rated interrupting capacity of 1000 amp. for the usual conditions of service.

These fuses were assembled for the tests with a standard 110-kv. Locke grading shield, which is made of steel strap material 2½ in. by ¼ in. in a flat-sided oval shape 24 in. by 40 in., designed for assembly with the long axis parallel with the line. The insulator string consisted of 11 Ohio Brass Company suspension line insulators (Cat. 25620). The grading ring was mounted at the bottom end and the fuses at the top as illustrated in Figs. 1 and 2.

For these tests the distance from the fuse tip to the ring was 37 in. This corresponds to a 60-cycle flashover of approximately 350 kv. and to an impulse flashover of approximately 1070 kv. based on an impulse wave which rises to its crest in ¼ to ½ microseconds and decreases to 50 per cent of crest value in 5 microseconds. This impulse value was chosen to be the same as the impulse flashover of seven 5¾-in. by 10-in. suspension line insulators, which is the recommended insulation level for a rated circuit voltage of 115 kv.

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(1) Report to Overhead System Committee of N.E.L.A., Chicago, 1927. 'Fused Arcing Horns and Grading Rings,'' by Philip Stewart, *Trans. A.I.E.E.*, Vol. 48, July, 1929, p. 891.

Ten tests were made, with the fuses illustrated in Fig. 3, beginning at an estimated current of 230 amp. and increasing in steps up to the maximum current of 3880 amp. To obtain the proper current for each test, an advance schedule was made out by the engineers of the Power Company giving the system set up and the current expected. The close agreement between the predicted and measured current values is quite remarkable. The arc was initiated by placing a wire between the ring and the fuse tip and then closing the back-up breaker. The time required for interruption, the current interrupted, and the predicted current are given in Table I. In this tabulation the first half cycle of current is given as the total current interrupted and is given as the square root of the sum of the squares of the symmetrical (a-c.) and offset (d-c.) components.

TABLE I

SUMMARY OF DATA OF THE FUSED GRADING SHIELD TESTS

Test No.	Cycles of Arcing	Cycles to Clear	INTERRUPTED CURRENT		Predicted Current
			Last Half Cycle	Total*	
1	..	4	222	315	228
2	..	3	335	388	410
3	..	8¾	...	639	775
4	...	2½	859	1112	1060
5	2¾	2¾	1390	1955	1530
6	1½	1½	2176	2878	2160
7	1¼	1¼	2561	3454	....
8	1¼	1¼	2741	4002	2970
9†	1¾	...	....	....	3700
10	1¼	1¼	3452	5120	3880

*First half cycle of current. Given as square root of sum of squares of symmetrical (a-c.) and offset (d-c.) components.

†No current wave on film.

The fuses interrupted the short-circuit successfully in all the tests and before the circuit breaker opened, without damage to any of the fuse tubes other than a slight burning of the terminals. In all but one test (No. 3 at 639 amp.) the time required for interruption was less than four cycles. In Fig. 4 are shown photographs of some of the tests, and in Fig. 5 are shown two of the oscillograms. On Tests Nos. 1 and 2, only the target at the bottom end of the fuse was blown out, while on all the other tests both ends were blown out. The grading ring was burned slightly. No burned spots were found on the conductor although the smoke and flame were blown down upon it.

Before and after each test, the distance from the fuse tip to the grading ring was measured. It was found that the variation in distance was of the order of one inch. This shows that this type of fuse support, which is simple, may be relied upon to maintain reasonably good adjustment of the flashover distance.

These tests indicate that the rupturing capacity of these fuses when used in this manner is in excess of 5120 amp. (effective).

Neither the lower nor upper limit of the rupturing capacity of the fuses when used in this manner was reached in these tests; and tests in the Schenectady Laboratory have demonstrated that the fuses will interrupt currents considerably below 300 amp. In the application of the fused grading shield assembly, it is not only necessary that the current be interrupted but also that it be interrupted before the relays have time to actuate the circuit breakers.

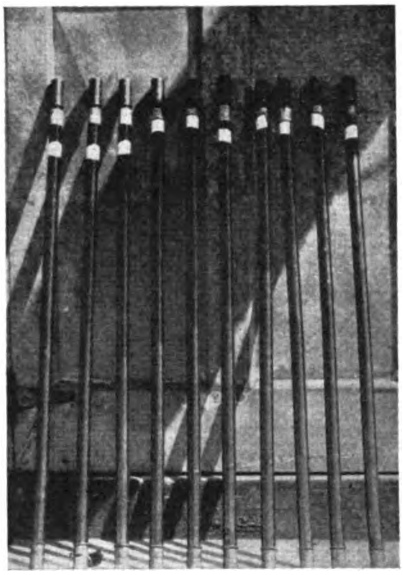


Fig. 3. The Ten Expulsion Fuses Used in Making the Tests

It seems reasonable to conclude that the fused grading shield assembly can be applied on 110-kv. lines with confidence when the short-circuit current to be expected is 1000 amp. or greater. It is probable that the fused grading shield assembly can be applied at lower values of current but it should be noted that on Test No. 3 at 600 amp., approximately, the arc held on for nearly nine cycles. If this test is not considered, the fused grading shield could be applied down to approximately 300 amp., based on this set of tests alone. (Factory tests indicate that the range of application can be extended below 300 amp.) For such an application it can be expected that the fuses will interrupt the current before the breakers have time to open, unless special high-speed relays are used.

The rupturing capacity of over 5000 amp. found in these tests appears quite high when compared with the normal rating of 1000 amp. However, the conditions of service are different. The 1000-amp. rating applies for the usual service conditions with a liberal factor of safety, and in which both ends of the fuse are positively connected to the circuit. When used in the fused grading shield assembly, one end of the fuse is free so that the fuse is actually in series with an air-gap. It is very likely that it is this air-gap which enables the fuse to rupture more current.

Furthermore, the normal rating of the fuses is based on tests in the Schenectady High Current Laboratory and it is known that tests in this Laboratory impose very severe service on the fuses.

The field of application for the fused grading shield assembly is its use along the line to permit flashover without outages, and its use at the end of the line to establish the reference insulation required for the particular line in question. In order that the device may function successfully, it is necessary that the arc always strike the end of the fuse. To accomplish this, the flashover voltage from the ring to the end of the fuse must be appreciably less than the flashover voltage from the ring to the top of the insulator string.

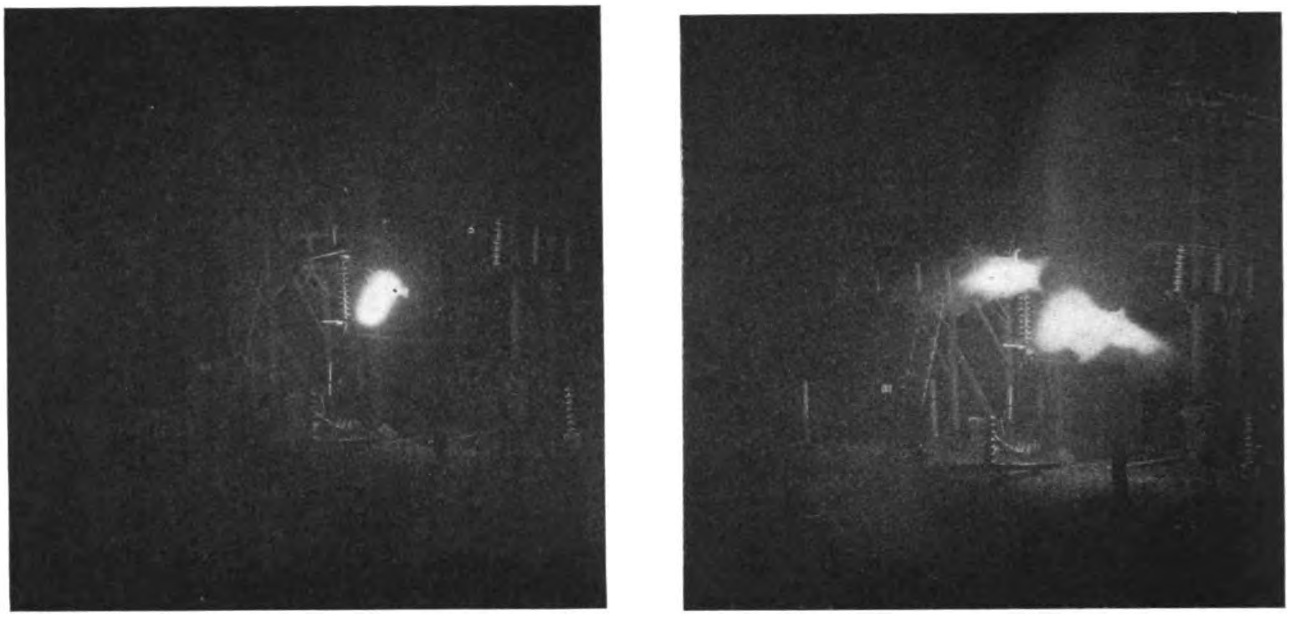


Fig. 4(a). Test No. 1. Initial current, 315 amp. Final current, 222 amp.

Fig. 4(b). Test No. 3. Initial current, 639 amp.

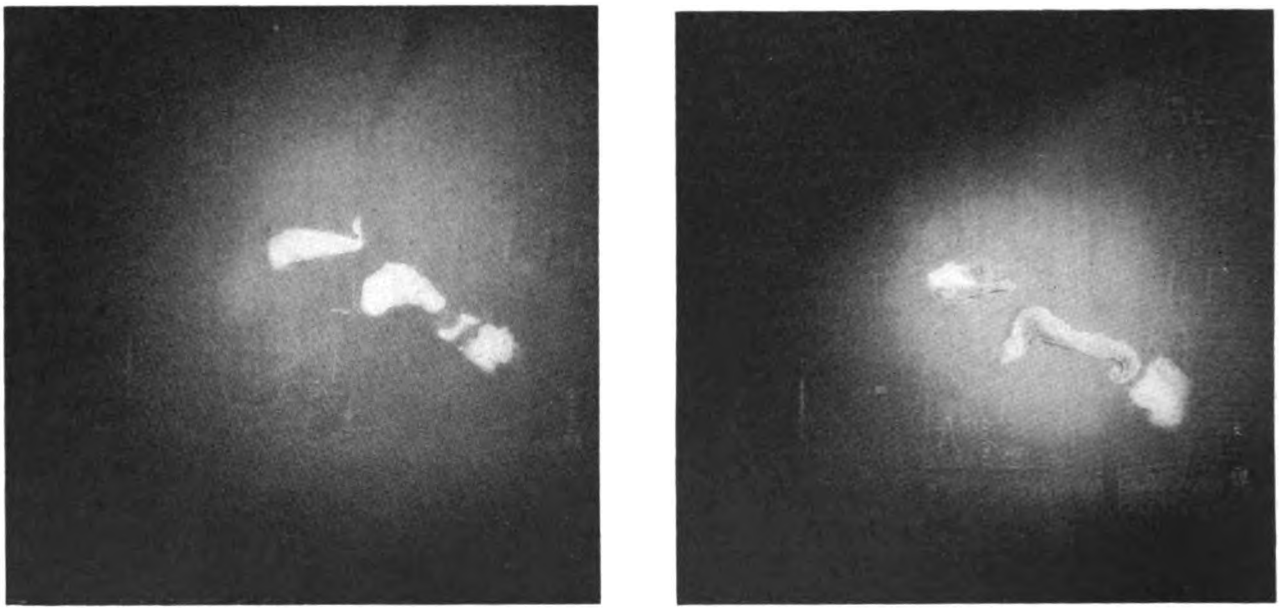


Fig. 4(c). Test No. 8. Initial current, 4002 amp. Final current, 2741 amp.

Fig. 4(d). Test No. 10. Initial current, 5120 amp. Final current, 3452 amp.

Fig. 4. Night Photographs of Four of the Ten Arc-rupturing Tests

In the application of the fused grading shield assembly to transmission lines one of two courses must be followed, either the flashover voltage must be reduced below that of the unfused insulator string or additional units must be added to maintain the flashover voltage. The minimum flashover voltage which might be considered should be higher than the voltages to be expected from switching surges. These voltages are of the order of 5.5 times normal line-to-neutral voltage and have 60-cycle flashover characteristics. Accordingly, the fused grading shield assembly when in place should have a 60-cycle flashover voltage in excess of this figure. To maintain the lightning flashover voltage on an existing line and at the same time establish a differential so that the flashover will always occur to the tip of the fuse, it is necessary to add units to the insulator string which results in decreased clearances to the tower for wind conditions. For a new line these requirements mean additional units and heavier tower structure, both of which involve additional expense. These considerations indicate that at the present time it is improbable that the fused grading shield assembly will be used throughout an entire line.

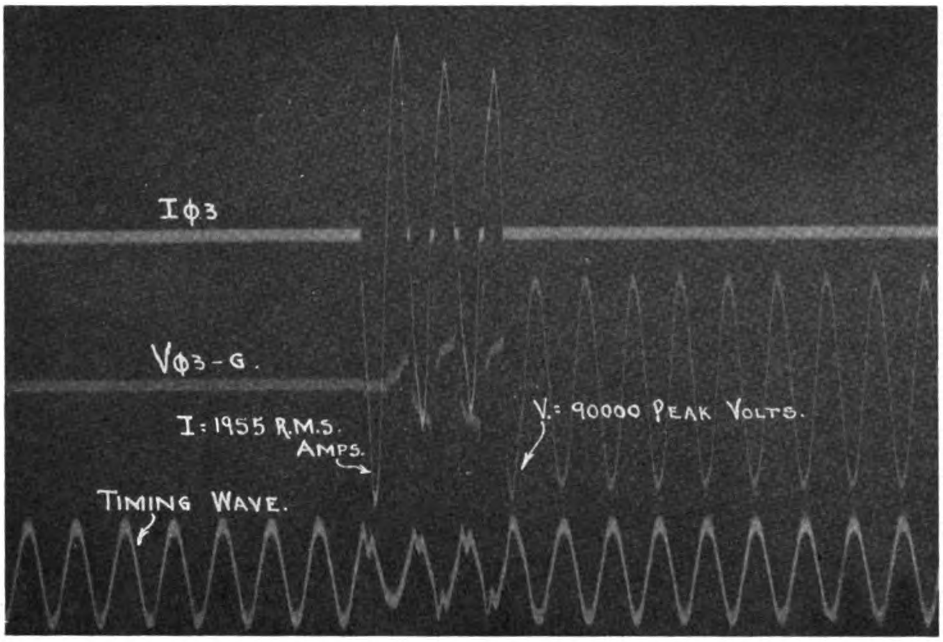


Fig. 5(a). Record of the line-to-ground short circuit (or arc current) and the voltage between that conductor and ground (initially zero) for Test No. 5

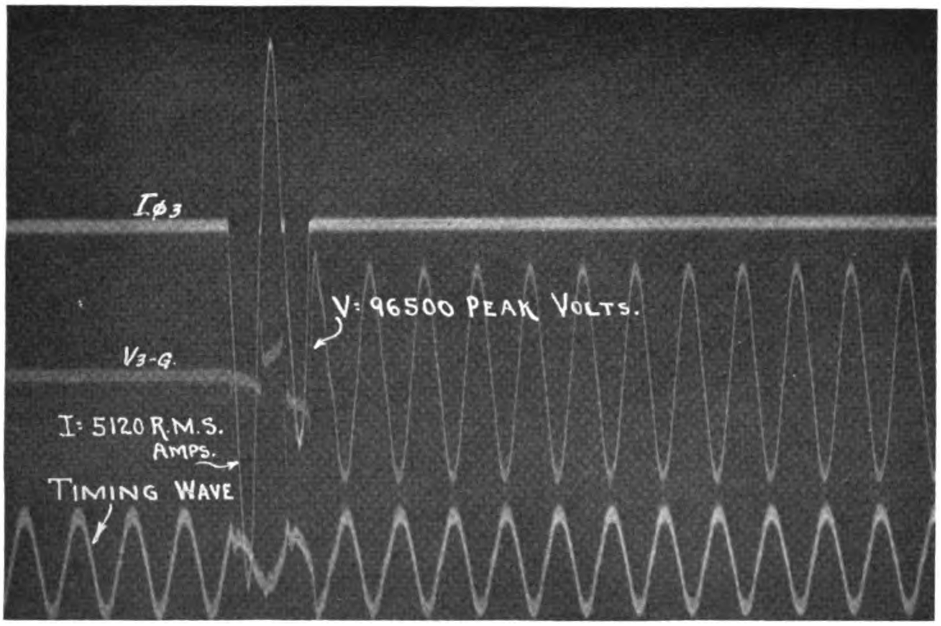


Fig. 5(b). Record for Test No. 10, similar to that shown in Fig. 5(a)

Fig. 5. Oscillograms of Two of the Tests. These general characteristics are typical of those of the other tests

Frequently there are short sections of line where flashovers are much more frequent than on the remainder of the line. Such a condition justifies special measures and would seem to offer a suitable opportunity for the application of the fused grading shield.

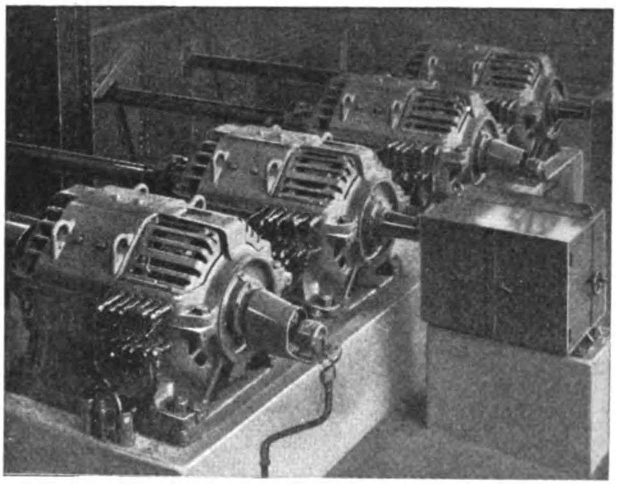
It is generally held that the insulation stress which will be imposed on station apparatus is dependent upon the insulation of the connected transmission lines. Since for any circuit voltage various operating companies may use different line insulations, it has been proposed to establish a reference insulation level for each standard rated circuit voltage. The station equipment will then be designed for the reference insulation level. The transmission line itself may be insulated to whatever extent the operating company desires but the reference insulation level should be established adjacent to the station.

This present tendency toward the coördination of line and station insulation recognizes the use of two methods of establishing the reference insulation level adjacent to a station. One of these is the use of the standard number of insulator units and the other is the use of a gap. The use of the lightning arrester is considered to be the most satisfactory method of protection, but in order that the best results be secured it is desirable that the insulation level be kept to proper values by either one of the previously mentioned methods. The use of the fused grading shield for the limitation of the line insulation to proper levels would permit the gap to flash over without an accompanying outage.

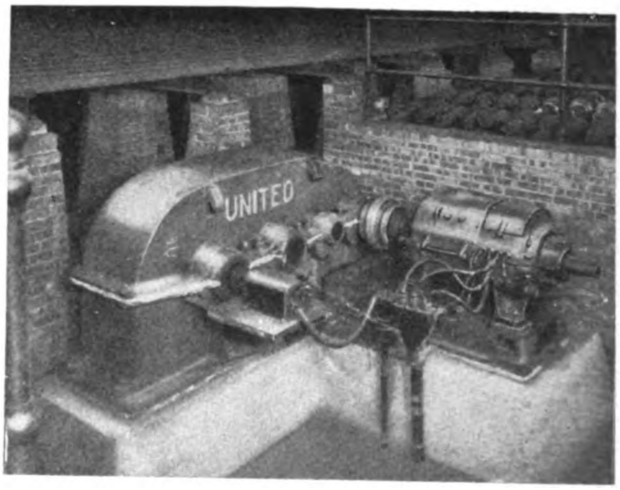
When the fused grading shield is used for this application, care should be taken to insure that the blowing of the fuses does not remove the limiting gap, which can be done by using enough fuses so that all will not be blown before replacements are made. This is best accomplished by the use of the fused shields on a few towers outside of the station, instead of the use of the recommended number of line insulators to establish the insulation level. If it is desired to have the relief gap in one place only, a fixed gap having the proper flashover value to establish the reference insulation level should be supplemented by fused gaps which would be set to have a lower flashover voltage than that of the fixed gap.

The writer wishes to acknowledge the assistance of the Alabama Power Company, which actually made the tests in its Bessemer Laboratory, and their courtesy in permitting the use of some of the photographs in this article.

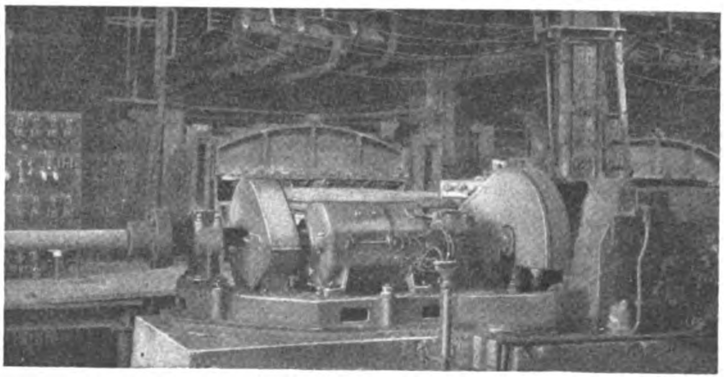
Steel Mill Motors on Duty



Group Driving a Continuous Skelp and Sheet-bar Mill



The Drive for a Cooling Bed of a Tie-plate Mill



A 35-hp. Motor Driving Pushers for Three Furnaces

Springs *vs.* Weights

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Lynn Works

The author points out the limiting features of dead weights and describes how these limits restrict their useful application in many cases. He describes many of the interesting features of springs and gives some of the general laws.
—EDITOR

SINCE the very earliest times mechanical devices have been utilized to aid man in his work: The lever, for example, utilized to move stones more readily; the sling or bail found useful in carrying such stones; then later the invention of the wheel for the first wheelbarrow; finally, such great inventions as the sling-shot and the bow and arrow; then a combination of these two forming the first engine of war, namely, the catapult.

The bow and arrow and the catapult were undoubtedly the first inventions which utilized the principle of elasticity. Since that time springs have been developed for innumerable purposes. They have been utilized in a multitude of ways. Still, even at this late date, it appears that certain applications of springs have been generally overlooked.

One great advantage in the utilization of springs for exerting force, as compared with dead weights for exerting the same force, is that the force of the spring may be directed in any plane whereas that of a stationary weight, being acted upon by the force of gravity, exerts its force only toward the center of the earth and requires additional mechanisms in order to redirect this force into any desired plane.

The fundamental difference between the characteristics of a spring and a dead weight is, of course, that the dead weight is virtually isodynamic, that is, the force toward the center of the earth is not appreciably changed by a change of position whereas the least change in deflection of a spring changes the resultant force of the spring; in other words, a dead weight has practically no scale or gradient, whereas a spring has a decided gradient which can be changed only by varying the number of its active turns, or else by redesigning the spring with relation to its mean diameter and the diameter of the wire of which it is wound.

For many applications it is desirable that a force should be applied of a certain magnitude, but that the movable mass should be as low as possible. This is especially true when considering the design, for example, of an instrument or governing device, so that the device may follow the changes which it is endeavoring to indicate with the least perceptible time lag.

Most instruments or governors should be so designed that they give a relatively broad scale reading for a small change in the conditions which they are indicating, and in many instances the conditions are likely to vary in magnitude quite rapidly. If, however, the low scale or gradient characteristics of a dead weight can be combined with the low inertia characteristic of a spring, many advantages will be gained. As a specific example, take a case in which a spring is utilized to restrain the motion of a piston, as in an engine indicator, in which case it is desirable that a very small pressure change should give a large motion of the piston after the pressure applied to the piston has already obtained a relatively high value. Such a device is usually referred to as an instrument with a latent or suppressed zero. The accuracy of such an instrument for rapid fluctuations in pressure depends entirely upon the absence of friction and the lightness of the moving parts, while the scale or range through which the instrument will move for a small pressure change depends entirely upon the scale or gradient of the loading spring.

In order that the maximum stress of a spring shall not exceed a certain safe value of torsional stress, a definite diameter of wire and a mean diameter of the helical spring must be selected to counteract the total force exerted by the piston. The gradient of such a spring can then be changed only by varying the number of active turns of the spring. In other words, to obtain twice the deflection of a given force, twice the number of active turns must be used. Therefore, to obtain a very low gradient the spring will necessarily have a large number of active turns.

It is obvious, however, that even an infinite number of active turns can never produce the isodynamic effect of a dead weight which, as before stated, has a scale or gradient of zero. Furthermore, a very large number of active turns will increase the effective mass of the spring because the mass of the spring is taken as one-half the total weight of the spring, remembering that one end of the spring remains stationary while the other is moved.

If it were possible to use a short, compact spring of very few active turns but with, obviously, a very high gradient and, without appreciably changing the maximum stress in the spring, to neutralize to any degree the gradient of the spring without increasing its effective mass, then a very desirable mechanism would be produced. Furthermore it might be advisable to neutralize the gradient of the spring until it was reduced to exactly zero for certain classes of work, making it, therefore, similar to a dead weight by being isodynamic, but arranging that the total moving mass might be a very small fraction of the mass of a dead weight of similar effective force.

As a spring is deflected it exerts a force due to its elasticity, reacting against the means which is being employed to deflect it. This force is directly proportional to the degree of deflection. The force is, therefore, following a straight line with relation to deflection.

For the sake of analysis let us say that the gradient of the spring may be called positive. Now, if we wish to reduce this gradient to zero it is obvious that we must add to this spring a device in which the gradient will be of exactly the same magnitude, will follow a straight line law, but will be of a negative characteristic. In other words, the more we deflect such a negative device the more it will want to go, and will build up a force increasing uniformly with deflection, but with the direction of the force in the same direction as the deflecting means which is moving it.

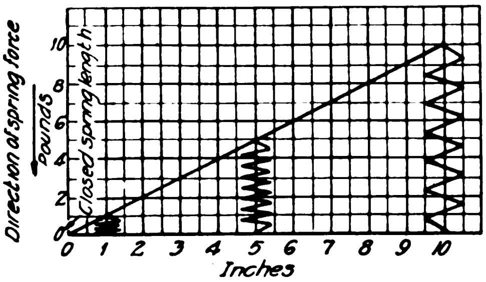


Fig. 1

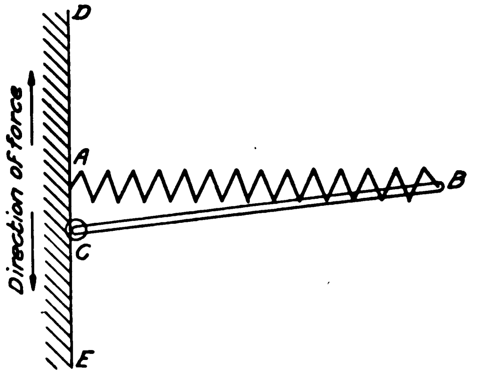


Fig. 2

If the gradient of this negative device is only one-half of the positive gradient of the spring, then obviously the resultant gradient of the combination will be one half of the original positive gradient of the spring alone.

Such a device has been developed and is in regular use for the adjustment of the gradient of springs used in pressure governing devices developed by the General Electric Company. The fundamentals of this device are based upon simple force diagrams.

In a force diagram it should be remembered that a line of any length has virtually a triple personality. In the first place it has a definite linear dimension. Secondly, it represents by its length a definite force after the relation of unit force to unit length has been decided upon; and, thirdly, it represents the direction of application of this force.

Suppose, then, that we draw a horizontal line AB of a length of 10 in., and let us assume that our unit of force is represented as 1 lb. equals 1 in., and let us say that this line represents the force exerted by a spring, the end A of which is held rigidly, and the end B has been drawn away from A by a length of 10 in. The spring, therefore, exerts a force in the direction of B to A of 10 lb.

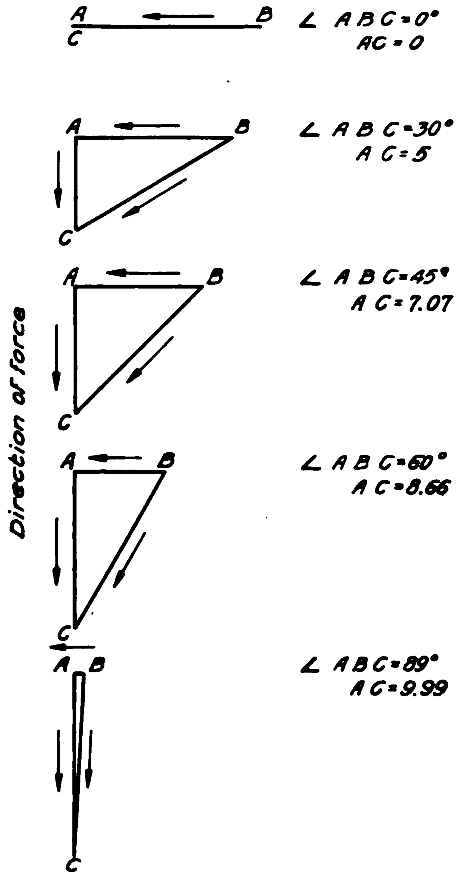


Fig. 3

If we should only have deflected this spring 5 in. then we should expect a force of only 5 lb. still acting in the direction of B to A.

Suppose, however, that the closed length of the spring was 1 in. In order that our conditions may be satisfied correctly, we must have wound into the spring sufficient initial tension so that a force of 1 lb. must be exerted before the spring can be opened at all. This is perfectly easy to do.

We can then represent the force of the spring with relation to its deflection by a straight line as shown in Fig. 1.

Now refer to Fig. 2. Here we have a horizontal spring AB 10 in. long representing a force of 10 lb. The end A is held rigidly. To the end B of the spring is attached a link whose length is 10 in. The opposite end of this link we will indicate as C. At the end of this link, at the point *C*, we will put a small roller which will run on a vertical track *DE*. We shall now represent the forces in this structure by a force diagram.

If the link is placed in an exactly horizontal position so that the angle between the link *CB* and the axis of the spring, which is line *AB*, is 0, we know that there is a compression force, due to the action of the spring, on the link *CB* of 10 lb., and while this may be in a very delicately balanced position yet there is, theoretically, no tendency for the point *C* to move up or down track *DE*, therefore the vertical component is 0.

Now draw a force diagram (Fig. 3) in which the angle *ABC* is equal to 30 deg. The line *BC* still has a length of 10 in., but the spring *AB* has been reduced from 10 to 8.66 in. The distance of the roller *C* in a vertical direction from *A* has now become 5 in. This, of course, is readily checked either graphically or by trigonometrical functions.

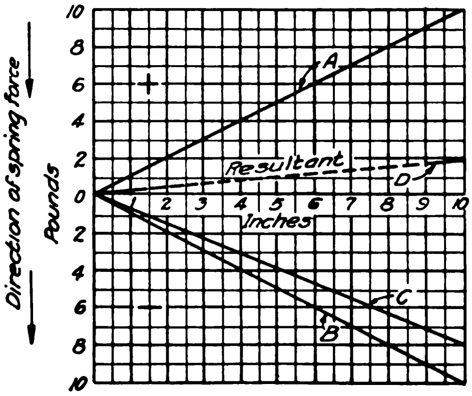


Fig. 4

Now make the angle *ABC* equal to 45 deg.: *CB* is still 10 in., *AB* is still further reduced to 0.707 in. and *AC* becomes 7.07 in. also.

Take another point where the angle *ABC* is 60 deg.: *CB* is 10 in., *AB* is reduced to 5 in. and *AC* has become 8.66 in.

Now let us go still further and assume an angle *ABC* equal to 89 deg.: *CB* is still 10 in.; *AB* has become 10 in. multiplied by the cosine of the angle, which is equal to 10×0.01745. Therefore *AB* is equal to 0.1745 in.; *AC* has become equal to 10 in. times the sine of the angle 89 deg., or 9.9985 in.

Now looking back over these figures we must remember this, that while we have called these results inches length of *AC* they also have the significance of pounds force; and from a force diagram we find that the direction of this force is from *A* to *C* whereas the direction of force of our spring is from *B* to *A*. Therefore, if we should plot the resultant figures in terms of pounds force, from *A* to *C*, for the different positions of our mechanisms, we produce a curve shown as *B* in Fig. 4 provided we have used a spring similar to the one originally selected, namely, with a gradient of 1 lb. per in. The spring itself of course is represented by a curve above the line similar to Curve *A* (Fig. 4), so that we have produced a spring mechanism with inverted elastic characteristic and the Curve *B* is a perfect straight line.

Referring now to Fig. 5, it will be seen how such a device may be applied. In the first diagram is represented a lever with a fulcrum at the middle. Ten inches to the right is attached a simple spring with gradient of 1 lb. per in. To the left of the fulcrum is a mechanism built up of four links with a horizontal spring across the diagonal. This horizontal spring also has a gradient of 1 lb. per in.

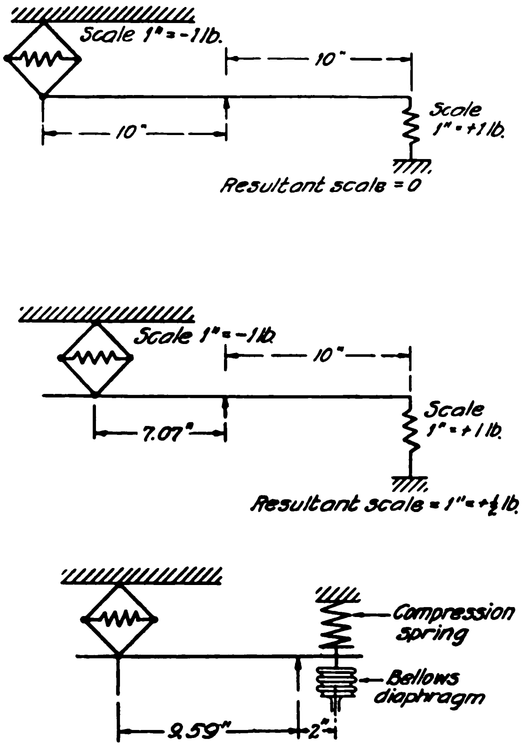


Fig. 5

(Note: These drawings are not reproduced in full scale.)

If we construct such a device we shall find that the lever will stay in any position we care to put it because it is following the laws which we have just stated. The force of the simple spring to the right is represented by Curve *A* in Fig. 4. As these forces are equal and opposite, the mechanism is, therefore, in a state of equilibrium at any position we care to put the lever.

We have therefore by this device entirely neutralized the gradient of the simple spring to the right. This would produce an overall characteristic which we call isodynamic, namely, it will exert the same force in any position, the force in this case being 0, but no change in force at any position. Such a device is as a rule of no particular value because it is unstable. It is necessary to neutralize only a portion of the gradient of the spring as a rule, leaving a small gradient in the overall mechanism.

In the second diagram (Fig. 5) the position of the gradient adjuster has been changed. It has been moved back to a distance of 7.07 in. from the fulcrum. In this position it will be found that only one-half of the gradient of the spring on the right has been neutralized. In other words, if we deflect the latter we shall find that the spring on the right has an apparent gradient of only ½ lb. per in. instead of 1 lb. per in. which we know actually exists.

The resultant gradient therefore varies as the difference in the gradient between the positive spring and the gradient adjuster times the square of their radii of action.

Take for another example a simple spring with a gradient of 100 lb. to the in. Let us place it at one end of a lever, which must be mounted on a fulcrum as shown in Fig. 5 but at a radius of 2 in. from the fulcrum. First we shall neutralize this gradient by means of the gradient adjuster whose horizontal spring has a gradient of 10 lb. per in. In order to find the radius at which this adjuster should be placed from the fulcrum we write the following formula:

$$\sqrt{\left(\frac{100\times 2^2}{10}\right)}=6.3246\text{ in.}$$

Now, supposing that we wish to reduce the gradient from 100 lb. to the inch down to 1 lb. to the inch using the same gradient adjuster, our formula becomes

$$\sqrt{\left(\frac{(100-1)\times 2^2}{10}\right)}=6.2929$$

Suppose that for a practical application we employ a bellows diaphragm (Fig. 5) which is loaded by a short, stiff spring to act as a pressure indicator or gradient, and let us assume the spring to have a gradient of 200 lb. to the in. and the bellows diaphragm a gradient of 40 lb. to the inch. The area of the bellows we will assume to be 10 sq. in. and the required motion to be ¼ in. to operate some valve mechanism or indicator. Without neutralization this will require a pressure change of $\frac{240}{4\times 10}=6$ lb. per sq. in. in order to overcome the combined gradient of spring and bellows.

But our desire is to reduce this gradient to obtain ¼ in. motion with only 0.25 lb. per sq. in. change of pressure.

Even the bellows gradient alone would require a pressure change of 1 lb. per sq. in. so that we must neutralize all of the spring gradient and three quarters of the bellows gradient.

By applying our negative 10 lb. per 1 in. gradient adjuster we find the following:

Radius of loading spring and bellows, 2 in.

Required overall gradient

$$\frac{0.25\text{ lb.}\times 10\text{ sq. in. area}}{\frac{1}{4}\text{ in. travel}}=10\text{ lb. per in.}$$

Therefore, radius of gradient adjuster will be

$$\sqrt{\left(\frac{(240-10)\times 2^2}{10}\right)}=9.59\text{ in.}$$

The advantages of an inverted elastic connection are therefore apparent.

Standard Graphical Symbols Used for Electric Power and Wiring

Attention is called to the availability of a report on "Standard Graphical Symbols used for Electric Power and Wiring," which report was developed in accordance with American Standards Association procedure by a Subgroup on Electric Power Wiring of a Subcommittee on Electrotechnical Symbols of the Sectional Committee on Scientific and Engineering Symbols and Abbreviations, and under the joint sponsorship of the American Association for the Advancement of Science, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the Society for the Promotion of Engineering Education, and the American Institute of Electrical Engineers.

The report comprises graphical symbols used for one-line and complete diagrams of electric power apparatus, instruments and relays, and system connection diagrams. The symbols are limited to apparatus usually met in electrical power engineering such as major electrical equipment in power houses, substations and transmission and distribution systems, and to system wiring diagrams. They are not intended to cover communication, railway, or other allied branches of electrical engineering.

In the belief that the undertaking has reached a stage at which the report should be circulated widely with a view to obtaining the opinions, criticisms, and suggestions of as many interested persons as possible, copies of the Report have been printed and are available on application to H. E. Farrer, Secretary of the Standards Committee of the American Institute of Electrical Engineers, 29 West 39th Street, New York City.

The Viscose Company's Power House at the New Rayon Manufacturing Plant, Meadville, Pa.

Steam and Electrical Requirements of the Manufacturing Process—The Large Quantities of Process Steam Needed Obtained by Extraction from the Turbines—Descriptions of Equipment for Coal and Ash Handling, and Generation of Steam and Electricity

By HARRY A. KULJIAN
Engineer, The Viscose Company, Marcus Hook, Pa.

THE Viscose Company's new Acetate Rayon Plant is located just outside of Meadville (Pa.), on the French Creek. It consists of numerous buildings, including boiler and power house, for the manufacture of Rayon by the acetate process.

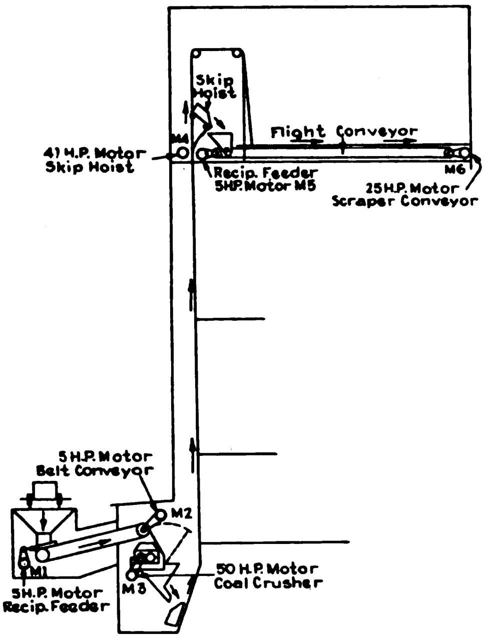

Skip Hoist
Flight Conveyor
M4
41 H.P. Motor Skip Hoist
Recip. Feeder 5HP. Motor M5
M6
25 H.P. Motor Scraper Conveyor
5 H.P. Motor Belt Conveyor
M2
M1
5H.P. Motor Recip. Feeder
M3
50 H.P. Motor Coal Crusher

Fig. 1. Diagram of the Raw Coal Handling System. The motors are started in the sequence *M6, M5, M4, M3, M2,* and *M1;* and should any motor stop during operation, those toward *M1* stop automatically and in sequence

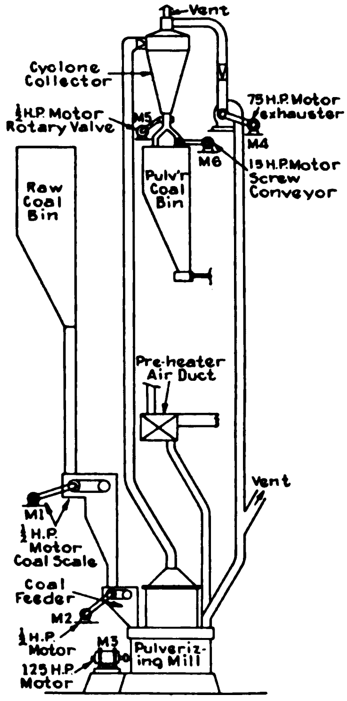

Vent
Cyclone Collector
½ H.P. Motor Rotary Valve
M5
75 H.P. Motor exhauster
M4
M6
15 H.P. Motor Screw Conveyor
Raw Coal Bin
Pulv'r Coal Bin
Pre-heater Air Duct
Vent
M1
½ H.P. Motor Coal Scale
Coal Feeder
M2
½ H.P. Motor
M3
125 H.P. Motor
Pulverizing Mill

Fig. 2. The Pulverized Coal Handling System. One screw conveyor feeds two units as shown, the conveyor running clockwise for one and counter-clockwise for the other. The sequence of motor starting is *M6, M5, M4, M3, M2,* and *M1.* If any motor stops, those toward *M1* stop automatically and in sequence

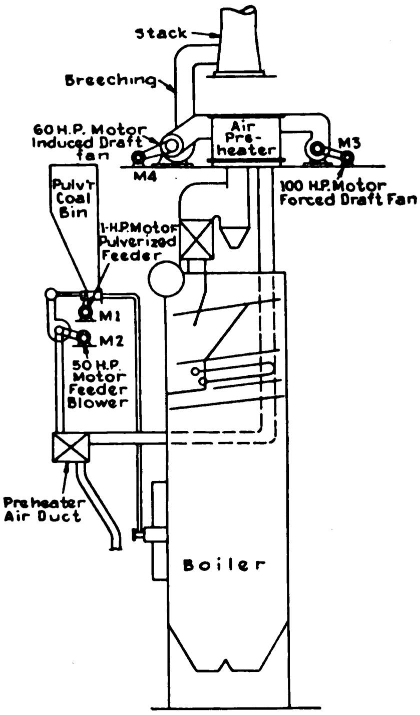

Stack
Breeching
60 H.P. Motor Induced Draft fan
Air Pre-heater
M3
M4
100 H.P. Motor Forced Draft Fan
Pulv'r Coal Bin
1-H.P. Motor Pulverized Feeder
M1
M2
50 H.P. Motor Feeder Blower
Preheater Air Duct
Boiler

Fig. 3. The Combustion System. The sequence in which the motors are started is *M6, M5, M4, M3, M2,* and *M1.* Any motor, on stopping, automatically stops those toward *M1* in sequence

A detailed study of the steam and electrical requirements of the process, when conducted on the scale of the present and ultimate plant, indicated that they could be fulfilled best by a local boiler and power house. Large quantities of process steam are required, and about 80 to 90 per cent of it is obtained at two different pressures by extraction from the turbines. The latent heat of evaporation of the remaining small quantity of turbine steam going to the condenser is of course lost in the circulating water; but all the heat of the steam that goes into the plant for process purposes is effectively utilized because this steam is later returned as condensate to the power house. The process steam demand necessitates an initial steam pressure of 450 lb. in order to generate a sufficient amount of electricity to supply the power requirements and at the same time furnish extraction steam at pressures and in quantities adequate for the various operations in the mill. The resulting design and layout of the boiler and power house are shown in Figs. 1 to 7.

The plant requirements necessitated the installation of three boilers, of 450 lb. pressure, each being capable of generating 150,000 lb. of steam per hour—the greater part of this steam passing part way through the turbines to generate a sufficient amount of electricity and then furnish enough extraction steam at 150 lb. and also 15 lb. pressure.

Boilers

The boilers are equipped with the bin system of pulverized coal equipment and low-speed mills were installed so that the total quantity of pulverized coal required for the 24-hr. day operation can be prepared during an 8-hr. shift; *i.e.*, each pulverized coal bunker in front of each boiler has sufficient capacity to run its boiler at 350 per cent rating for 24 hr. Each boiler is equipped with three turbulence-type burners; and each burner is fed independently by a variable-speed motor operating from 500 to 2000 r.p.m., in order to obtain the desired flexibility of steam generation for the day-and-night operation of the boilers.

The furnace of each boiler is so designed that it contains practically 8000 cu. ft. of furnace volume, 640 sq. ft. of water-cooled wall on each sidewall, 500 sq. ft. on the bridge wall, and 227 sq. ft. of screen between the furnace and the ash-hopper bottom. This gives 20 per cent of water-cooled surface per boiler, each boiler containing 10,477 sq. ft. of heating surface. The front wall of the furnace is a refractory wall to support combustion in the furnace when the boiler is operating at low rating.

The furnace volume is designed for the liberation of 25,000 B.t.u. per cubic foot per hour with a coal analysis as follows:

B.t.u.	Volatile	Fixed Carbon	Ash	Sulphur	Kind of Coal	District
12,682	36.22%	50.95%	12.83%	4.3%	Slack	Pittsburgh

When these boilers were put in operation, the steam generation requirements ranged from 15,000 to 18,000 lb. per hour; and yet at this low output the combustion in the furnaces was maintained without difficulty.

Each boiler is equipped with Babcock & Wilcox lower-deck superheaters, each having 1835 sq. ft. of heating surface to give a superheat of 150 deg. at 450 lb. pressure when producing 90,000 lb. of steam per hour.

Associated with each boiler is an air preheater which reduces the temperature of flue gas from 638 deg. to 300 deg. F. when the boiler is generating 90,000 lb. of steam per hour. The temperature of the air from the forced draft fan is thus raised to 325 deg. F.

Steam Requirements

As much flexibility as possible has been introduced to insure the availability of sufficient process steam when the boiler house and power house are in operation. In addition, steam is taken directly from the main of the auxiliaries, as shown in Fig. 5, and connected to a desuperheater to maintain the temperature as well as the pressure of the 150-lb. process steam. If the demand for the 15-lb. steam increases, steam at 150 lb. going through a pressure-reducing valve will pass a sufficient quantity into the 15-lb. line to maintain the pressure. In addition, also, there is a heat-balanced line from the 15-lb. main to the feed-water heater and an endeavor will be made to maintain 5 lb. pressure at the heater. Under any operating condition there would always be a shortage of low-pressure steam at the heater because all the boiler and power-house auxiliaries are driven electrically. The main object is not to have an excess of steam from the boiler-house auxiliaries, since the 15-lb. line is always kept within about one pound drop. This arrangement eliminates any low-pressure steam from the auxiliaries going into the atmosphere. Practically all the

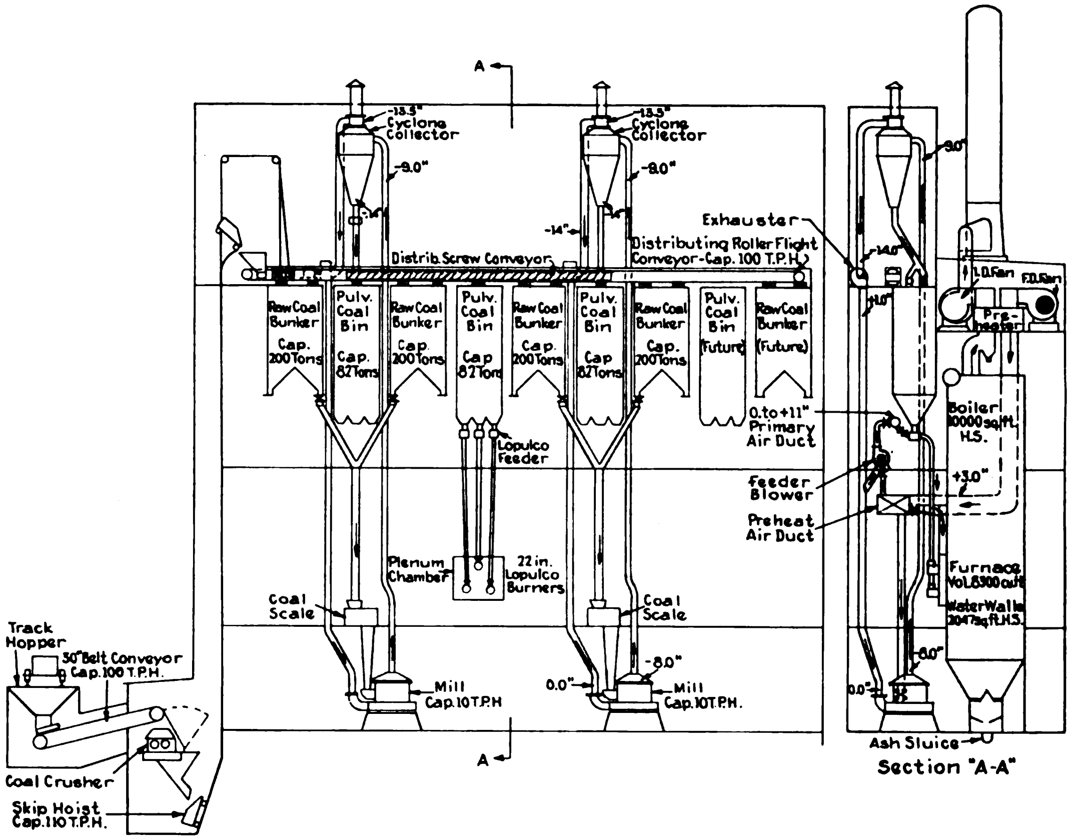

A
-13.5"
Cyclone Collector
-9.0"
-14"
Distrib. Screw Conveyor
Exhauster
Distributing Roller Flight Conveyor-Cap. 100 T.P.H.
Raw Coal Bunker Cap. 200 Tons
Pulv. Coal Bin Cap. 82 Tons
Pulv. Coal Bin Future
Raw Coal Bunker (Future)
0.to+11" Primary Air Duct
Lopulco Feeder
Feeder Blower
Preheat Air Duct
Plenum Chamber
22 in. Lopulco Burners
Coal Scale
Mill Cap. 10 T.P.H.
0.0"
-8.0"
Track Hopper
30" Belt Conveyor Cap. 100 T.P.H.
Coal Crusher
Skip Hoist Cap. 110 T.P.H.
9.0"
-14.0"
+1.0"
I.D. Fan
F.D. Fan
Pre-heater
Boiler 10000 sq. ft. H.S.
+3.0"
Furnace Vol. 8300 cu. ft.
Water Walls 2047 sq. ft. H.S.
Ash Sluice
Section "A-A"

Fig. 4. Diagram of the Coal Handling Equipment from the Track Hopper to the Burners

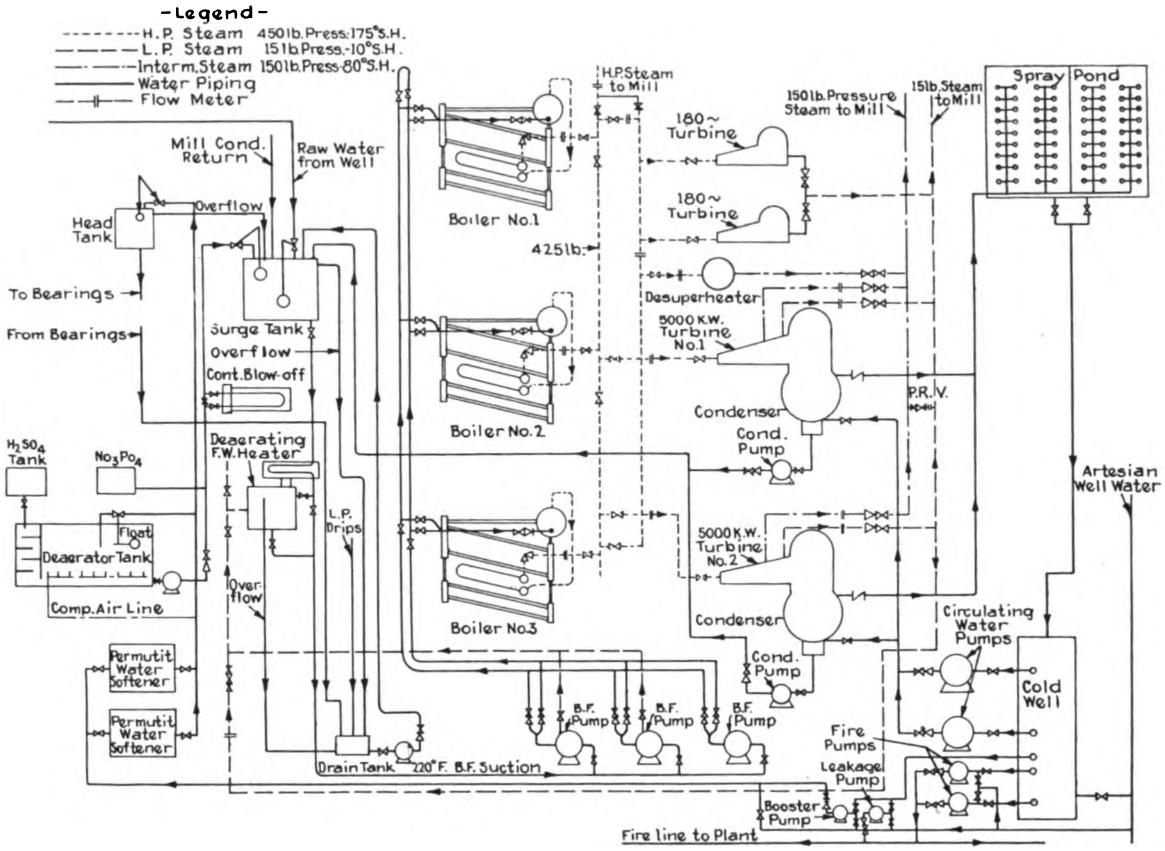

-Legend-
H.P. Steam 450lb.Press.175°S.H.
L.P. Steam 15lb.Press.-10°S.H.
Interm.Steam 150lb.Press.80°S.H.
Water Piping
Flow Meter
Mill Cond. Return
Raw Water from Well
Head Tank
Overflow
To Bearings
From Bearings
Surge Tank
Overflow
Cont.Blow-off
Deaerating F.W.Heater
H_2SO_4 Tank
Na_3PO_4
Float
Deaerator Tank
Comp.Air Line
Over-flow
L.P. Drips
Permutit Water Softener
Permutit Water Softener
Drain Tank
220°F. B.F. Suction
Boiler No.1
Boiler No.2
Boiler No.3
425lb.
H.P.Steam to Mill
180~ Turbine
180~ Turbine
Desuperheater
5000 K.W. Turbine No.1
5000 K.W. Turbine No.2
Condenser
Condenser
Cond. Pump
Cond. Pump
B.F. Pump
B.F. Pump
B.F. Pump
150lb.Pressure Steam to Mill
15lb.Steam to Mill
P.R.V.
Spray Pond
Artesian Well Water
Circulating Water Pumps
Cold Well
Fire Pumps
Leakage Pump
Booster Pump
Fire line to Plant

Fig. 5. Schematic Piping Diagram of the Boiler and Power House

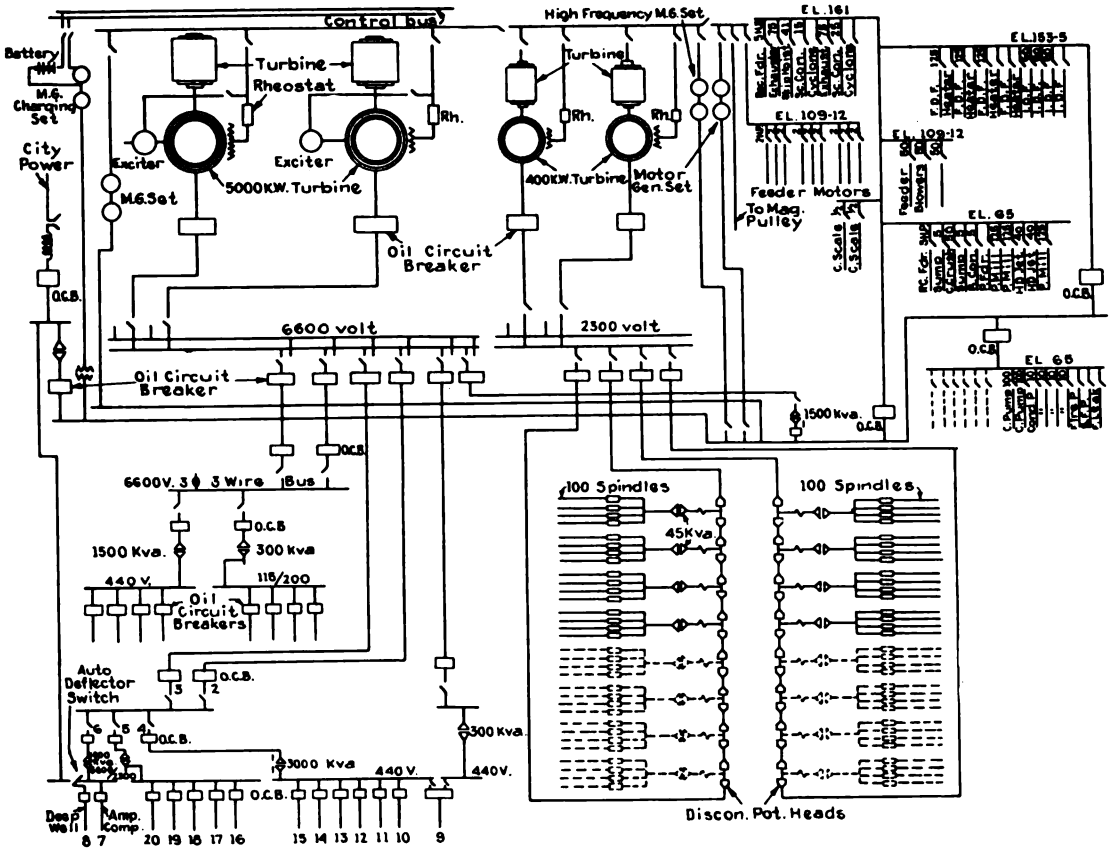

Control bus
Battery
M.G. Charging Set
City Power
O.C.B.
Turbine
Rheostat
Rh.
Exciter
Exciter
M.G.Set
5000KW. Turbine
Oil Circuit Breaker
High Frequency M.G.Set
Turbine
Rh.
Rh.
400KW.Turbine
Motor Gen.Set
6600 volt
2300 volt
Oil Circuit Breaker
O.C.B.
1500 Kva.
EL.161
EL.153-5
EL.109-12
EL.109-12
EL.65
EL 65
O.C.B.
Feeder Motors
To Mag. Pulley
C.Scale
C.Scale
6600V. 3φ 3 Wire Bus
O.C.B.
1500 Kva.
300 Kva
440 V.
115/200
Oil Circuit Breakers
Auto Deflector Switch
O.C.B.
3
2
6
5
4
O.C.B.
Deep Well
Amp. Comp.
8 7
20 19 18 17 16
3000 Kva
440 V.
O.C.B.
15 14 13 12 11 10
9
300 Kva
440V.
100 Spindles
45Kva
100 Spindles
Discon. Pot. Heads

Fig. 6. Single-line Wiring Diagram of the Station

discharges from the low-pressure drip lines, drain lines, and high-pressure or intermediate-pressure drip lines are received in a condensate tank and are returned directly into a surge tank in order to reduce the make-up steam to a minimum.

Water Purification for Make-up

The percentage of make-up in this process is so high that the space requirements for an evaporation equipment would have been prohibitive; for which reason Zeolite water-softening equipment was installed at the power-house, and it furnishes a sufficient quantity of make-up.

Since all the calcium and magnesium salts are changed to sodium salts through this softening process, a sulphuric acid feed is being used to neutralize the sodium alkalinity. At first a sodium sulphate tank was installed to carry a sulphate-to-carbonate ratio of 3:1, but the operating cost was so high that it was later changed to the acid feed.

Raw Coal Handling

The raw coal handling system is illustrated in Fig. 1. The track hopper is of the double type, having a length of 34 ft. and a width of 14 ft., with double reciprocating hopper on the bottom so that a whole carload of coal can be dumped into the track hopper without moving the car. From the reciprocating feeder on the bottom of the hopper, the coal is transferred into the crusher by means of a belt conveyor which has a magnetic pulley for separating all foreign iron from the coal. It is then discharged from the crusher into the skip-hoist pit, from where the coal is elevated to the top of the boiler-room floor, and from there a reciprocating feeder passes it into a scraper conveyor that distributes it into the raw coal bunkers from one end of the power house to the other.

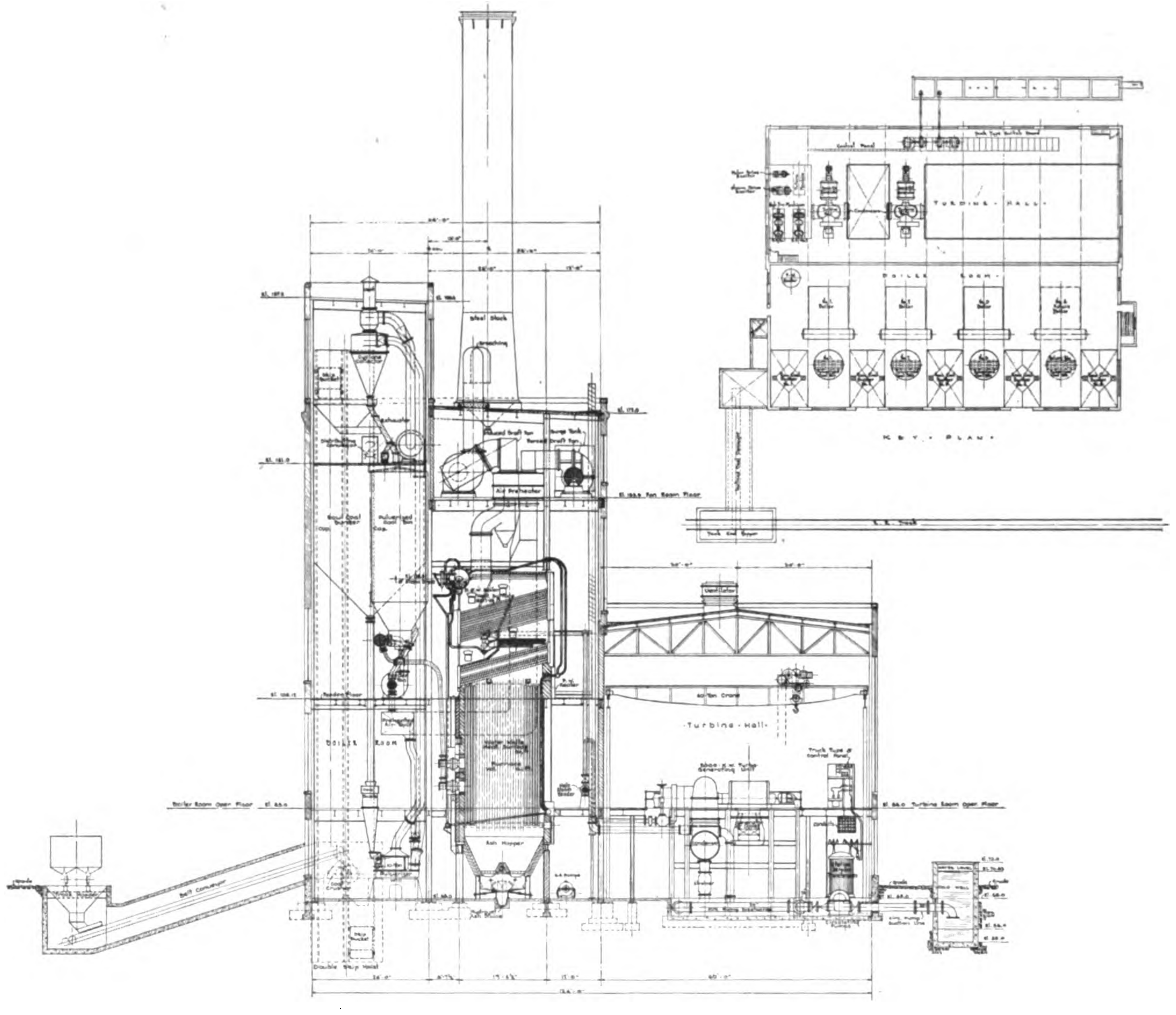

Steel Stack
Breeching
Induced Draft Fan
Surge Tank
Forced Draft Fan
Air Preheater
Raw Coal Bunker
Pulverized Coal Bin
Boiler Room
Ash Hopper
Coal Crusher
Belt Conveyor
Double Skip Hoist
Turbine Hall
Boiler Room
Key Plan
Truck Coal Hopper
Fan Room Floor
Ventilator
40 Ton Crane
·Turbine·Hall·
Turbo Generating Unit
Truck Type & Control Panel
Turbine Room Oper. Floor
Circulating Pumps
Water Level

Fig. 7. Section and Key Plan of the Meadville Power Plant of the Viscose Company

Pulverized Coal Preparation

The pulverized coal preparation system is shown in Fig. 2. The coal from the raw coal bunker goes through a weighing scale, thence from the scale into the feeder of the pulverizer, and from the pulverizer through a cyclone collector. It can then be discharged into the pulverized coal bunker directly underneath the cyclone collector or can be conveyed into the other pulverized coal bunkers in front of the other boilers by means of a screw conveyor. The pulverized coal system includes two 10-ton Raymond pulverizing mills. In case one pulverizer is out of commission or down for repairs, the other one can be used and pulverized coal can be distributed to the other side of the cyclone collector by changing the direction of rotation of the screw conveyor.

Both the raw and pulverized coal handling drives are electrically interlocked, so that in case any one of the motor circuits is opened the motors preceding it will be tripped off the circuit, thus preventing an accumulation of coal that could not be handled.

The three boilers are completely equipped with automatic combustion-control equipment to vary the speed of the forced and induced-draft fans as well as to operate the position of their dampers. The speed of the feeder on each burner is also manipulated by the combustion control. Any one of the boilers can be operated by either combustion control or manually. The electric drives on the forced and induced-draft fans, feeder, and feeder blowers are electrically interlocked as specified in Fig. 3 to prevent any possible chance of danger.

Ash Handling

After due consideration of various types of ash-handling methods, a selection was made of the Hydrojet system as manufactured by the Allen-Sherman-Hoff Company. This consists of an air-cooled ventilated furnace bottom, refractory-lined furnace, bottom gates, and an ash-receiving chamber attached directly to the furnace bottom. The ash is fed at intervals into a sluiceway which carries it to a sump and then it is discharged to the "fill" by means of vertical 6-in. ash pumps. These pumps are specially designed for handling ash and have an auxiliary impeller cast integral on the main impeller. This auxiliary impeller has a clear water suction and discharges clear water into the main volute of the pump at a higher pressure than is in the main volute of the pump. Thus the wear due to the ash water is on only one side of the main impeller and will considerably reduce the repair and maintenance of the pump.

Electrical Units

The power house consists of two 5000-kw. generators, one of which will carry the entire load of the manufacturing activities and the other one will be a 100 per cent spare. In case there should be an extension of the manufacturing operations which would require an additional 5000-kw. generator, the two present machines would be placed on the line and another one would be installed for a reserve in case either one of the other machines should be down for repairs.

Each substation is fed by two feeders, one feeder being large enough to carry the entire load and the other one a duplicate for emergency. Under ordinary conditions of operation, both of these feeders from the power house to the substation are used to carry current. By thus dividing the load current between the feeders, the I^2R losses are reduced.

About 60 per cent of the motors in the plant are of the induction type and for 440-volt operation; the larger synchronous motors are of 2300 volts. These large motors will be used for power-factor correction. The generator voltage is 6600 volts on account of the interrupting capacities of the switches in case of future expansion. All the switches on the 6600 and 2300-volt buses are mounted on truck-type panels, and all the 440-volt bus switching equipment is on open-type panels.

The feeder for the auxiliaries in the power house is taken directly from the 6600-volt main bus through a transformer to the 440-volt distribution line. For emergencies there is a tie line from the city, which is also connected to the low-tension bus for the station auxiliaries.

The control panel is entirely push-button operated, and derives its supply from a small motor-generator set across which is floated a storage battery that for a short period will furnish control energy in case of failure of the motor-generator set.

Performance of Thyrite Arresters for Any Assumed Form of Traveling Wave and Circuit Arrangement

General Equations—Data Required for Computations—The Thyrite Arrester—Thyrite Arrester Performance—Special Conditions

By K. B. McEACHRON and H. G. BRINTON
Lightning Arrester Engineering Department, Pittsfield Works
General Electric Company

When studying lightning arrester application and performance it is very desirable to be able to determine the exact shape of the volt-time and ampere-time curves of the arrester for the conditions under which it is to operate in service. Excepting the unusual case of direct strokes at the point where the apparatus is connected, the insulation of the transmission line will determine the magnitude of the impulse against which the arrester must protect the connected apparatus. If the impulse rises above the 60-cycle flashover value of the insulators, flashover may occur on either the front or the tail of the wave, depending upon the magnitude or crest of the wave and the duration of the impulse above the 60-cycle flashover value. In this article no attempt will be made to analyze the conditions which may result in an insulator flashover. Rather, a certain wave will be assumed and it will be shown how arrester performance may be determined for any form of traveling wave.

General Case: Arrester Connected Between Two Surge Impedances

A lightning arrester may be considered as a resistance which has the property of decreasing its ohmic resistance as the potential across it increases. In Fig. 1 is shown a schematic diagram of the general case of a traveling wave E_1 approaching an arrester over a line or lines of equivalent surge impedance Z_1 and passing the arrester into a line or lines of equivalent surge impedance Z_2.

The general equations of this circuit are:

$$E_A = E_2 = E_1 + E_r \tag{1}$$

$$I_A + I_2 = I_A + \frac{E_A}{Z_2} = I_1 - I_r \tag{2}$$

Multiplying Equation (2) by Z_1 gives

$$Z_1 I_A + \frac{Z_1}{Z_2} E_A = E_1 - E_r \tag{3}$$

Adding Equations (1) and (3)

$$E_A \left(1 + \frac{Z_1}{Z_2}\right) + Z_1 I_A = 2E_1 \tag{4}$$

where

E_A, I_A = arrester voltage, current
E_r, I_r = reflected wave voltage, current
E_2, I_2 = outgoing wave voltage, current
E_1, I_1 = incoming wave voltage, current

Equation (4) is the general equation giving the relationship between the arrester voltage and the traveling wave voltage.

In the special case of the arrester at the end of the line, Z_2 equals infinity and Equation (4) becomes:

$$E_A + Z_1 I_A = 2E_1 \tag{5}$$

When Z_2 equals Z_1 then Equation (4) is

$$2E_A + Z_1 I_A = 2E_1 \tag{6}$$

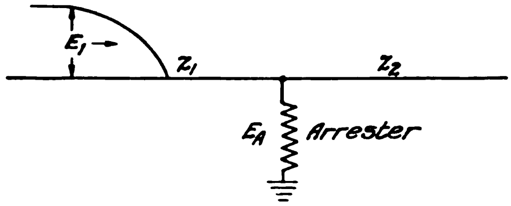


Fig. 1. Arrester Connected to Transmission Line; General Case

In general, if $Z_2 = nZ_1$ the equation becomes

$$\left(1 + \frac{1}{n}\right) E_A + Z_1 I_A = 2E_1 \tag{7}$$

If no arrester is present then the arrester current is zero and Equation (4) is

$$E_A = E_2 = \frac{2E_1}{1 + \frac{Z_1}{Z_2}} \tag{8}$$

As stated before, Z_1 and Z_2 are the equivalent single-wire surge impedances of the incoming and outgoing circuits connected to a single-pole arrester. When Z_1 or Z_2 consists of two or more conductors carrying identical waves which reach the arrester at the same instant, then the equivalent surge impedance is the reciprocal of the sum of the reciprocals of the individual surge impedances. In such a case, however, the individual surge impedance of a conductor is affected by the presence of another conductor also carrying an impulse, if near enough to be electrostatically or electromagnetically coupled. The individual surge impedances are increased if the surges are of the same sign and decreased if the surges are of opposite sign.

With conductors running parallel, each connected to its own pole of an arrester as in a three-phase circuit, the surge impedance of each conductor is increased over the isolated wire surge impedance if the three waves are similar, as is usually the case. This increase in surge impedance reduces the amount of current it is necessary for each pole of the arrester to carry for a given reduction of the incoming wave potential at the arrester. When a surge arrives at a point where an arrester is connected, and finds other surge impedances into which it can flow in parallel with the arrester, the total discharge current from Z_1 is increased by the presence of the parallel surge impedance Z_2. As a result of the increased current in Z_1 the voltage across the arrester and connected apparatus during the discharge is less than it would have been had the parallel surge impedance Z_2 not been present.

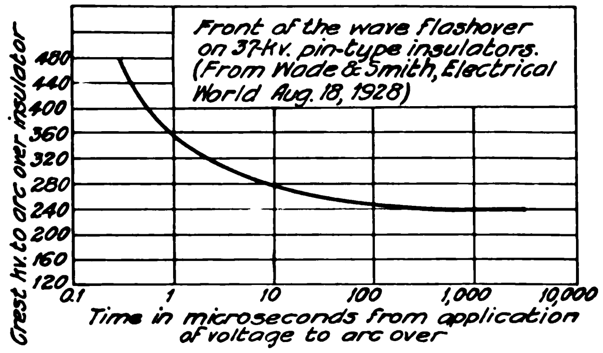


Fig. 2. Typical Curve Showing Breakdown Characteristic of Insulation

The surge impedance Z_1 plays a very important part in the arrester performance, as shown by Equation (4). The arrester current causes a voltage drop in the surge impedance Z_1 and thus reduces the voltage at the arrester and the apparatus to be protected. The part which the surge impedance plays should be taken into account when laboratory tests of lightning arresters are being considered. A correct interpretation of the results cannot be made unless this is done.

Data Necessary for the Calculation of Arrester Performance

The operation of an arrester having a series gap or its electrical equivalent may be conveniently considered as divided into two phases. The first phase is the gap breakdown. The second phase is concerned with the *IR* drop across the arrester while passing current. In order that correct results may be obtained it is necessary to know, when calculating the arrester performance curves, how these phases of arrester operation are affected by rate of voltage rise, rate of current rise, maximum current, and duration of current. If the impulse ratio of the series gap or its equivalent is not equal to unity for all wave fronts, it is necessary to obtain a curve based on test results which shows the arrester gap breakdown potential plotted against the time taken to reach breakdown on the front of the wave. The usual form of such a curve is hyperbolic. A curve of this nature taken of a 37-kv. pin-type insulator is shown in Fig. 2. Unless special means have been employed to reduce the impulse ratio, all gaps exhibit this characteristic in varying degree. The impulse ratio of very small gaps is likely to be quite high.

The *IR* drop characteristic of an arrester may be affected by the rate of current rise or by the duration and the magnitude of the current. Unless it can be shown that the *IR* characteristic is unaffected by rate of current rise, a curve should be obtained giving the *IR* drop for various rates of current rise. This is necessary, because in the traveling wave the current reaches its crest in the same time that the voltage reaches its crest and thus the rate of current rise may be very rapid. Arresters having a loop in the volt-ampere curve are likely to be affected by the rate of current rise. In such an arrester two values of potential are found for the same current and the difference between the two values must be the effect of time and current. It can be readily seen that such an *IR* characteristic is likely to be affected by the duration of the current and also its magnitude.

The Thyrite Arrester

The Thyrite arrester is peculiarly adapted to the calculation of arrester performance, since the volt-ampere curve has no loop, and it can be shown quite readily that it is not affected by rate of current rise; nor is it affected by the duration of the transient so long as the transient does not last long enough to heat the entire volume of the Thyrite very greatly. The duration required for such heating is many times the length of any waves due to natural lightning recorded up to this time. Laboratory tests of Thyrite disks under extreme conditions indicate that no difficulty need be anticipated from the standpoint of duration of the impulse. The factor of safety from this standpoint is very high indeed.

Thyrite has a fixed volt-ampere characteristic, which is illustrated in Fig. 3. The volt-ampere characteristic is seen to be a straight line on log-log paper from 0.1 amp. to 10,000 amp. A cathode-ray oscillogram of the same 11.5-kv. arrester unit is also shown which checks the plotted curve very closely. This is true whether the applied potential is 60 cycles or a transient reaching its crest in one microsecond or less. The characteristics are fixed and do not depend upon the previous history of the discharge but only on the voltage at the instant under consideration. A volt-ampere curve such as the one given in Fig. 3 supplies all of the necessary information concerning the *IR* characteristic of the arrester, so that its performance may be readily calculated.

The Thyrite Arrester Gap Unit

The Thyrite arrester is built in units rated 11.5 kv. Each unit is complete in itself, containing one gap unit and eleven Thyrite disks three-quarters of an inch thick and six inches in diameter. If the normal operating potential of 6.6 kv., which is the arrester unit rating divided by the square root of three, is applied to the eleven disks, a crest current of about four amperes (2.1 amp. effective value) will flow. If the applied potential is increased to a value equal to the arrester rating (which is based on line-to-line voltage) the crest current will be about 28 amp. (14.8 amp. effective). However, this would only happen with one line grounded. The gap structure stops the flow of follow current after the impulse, in case the impulse strikes at such a time on the 60-cycle wave that follow current flows. The current interruption is greatly aided by the resistance characteristics of the Thyrite disks. For example, when the voltage has dropped to one-half crest value the current has dropped to one-twelfth crest value.

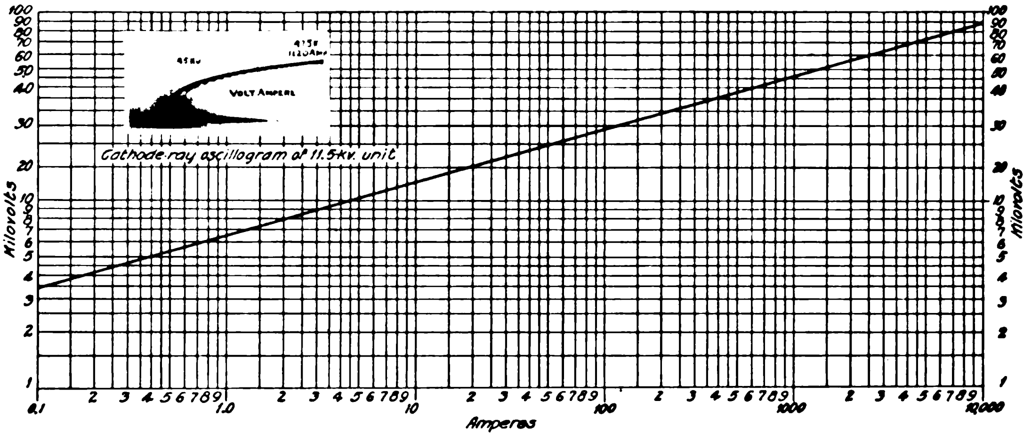


Fig. 3. Volt-ampere Characteristic of a 11.5-kv. Thyrite Lightning Arrester for Grounded-neutral Circuits

If a single gap were used, difficulty would be experienced in breaking the current in one half-cycle. If, however, the arc is broken up into a series of small arcs, it becomes possible to stop the arc with Thyrite in series before the end of the half-cycle of applied line potential. To provide an adequate factor of safety, twelve gaps are used, each gap being set for about 2500 volts. Connecting twelve gaps in series is similar to connecting twelve suspension insulator units in series, in that the potential required to spark over the twelve is considerably less than twelve times the individual spark potential. If still more gaps are added, a number is finally reached after which the addition of more gaps does not increase the spark potential of the group. Where it is desired, as in the Thyrite arrester, to connect as many units as necessary in series, some means must be provided for keeping the voltage distribution across the gaps in a reasonably straight line.

While it is necessary to provide a straight-line distribution at system frequency, it is highly desirable that the impulse distribution be non-uniform. This is particularly important when small gaps are used, since they have a high individual impulse ratio with steep wave fronts applied. To keep the impulse spark potential approximately equal to the 60-cycle spark potential, the voltage distribution along the series gaps must be made selective with respect to frequency. An impulse whose crest potential is reached in one microsecond will have an average rate of voltage rise approximately 4,000 times that of a 60-cycle wave having the same crest potential.

For the purpose of changing the voltage distribution, resistance and capacity only are available as the practical requirements are such that inductances could not well be used. Fig. 4 illustrates a test arrangement in which the sphere gaps were each set for 5-kv. crest and a resistance and capacitance so proportioned that at 60 cycles the current through the capacitor was one unit, while the current through the resistor was forty units. Thus at 60 cycles the resistance controlled the situation and the gaps sparked at 10 kv. crest. When an impulse was applied having a rate of potential rise about 4,000 times that of the 60-cycle wave, the current through the capacitor became 4,000 units or about 100 times as great as that through the resistance, and thus the capacity determined the distribution. Thus the voltage was concentrated on one gap causing the gaps to break down in succession so that the gaps repeatedly sparked at 5.6 kv. on the front of the wave, giving an impulse ratio of 0.56.

The next problem was to incorporate this principle in a gap structure containing twelve gaps and get it in a small space. Fig. 5 shows a schematic diagram of the gap unit. A resistance is bridged across each pair of gaps, which gives the correct distribution of potential for the normal operating frequency. With capacitances connected between alternate gaps and ground, as shown, the distribution becomes non-uniform with steep wave fronts when the capacity current becomes large with respect to the resistance current. The capacity currents through the gaps nearest the line end are large compared to the capacity currents through the gaps on the ground end, thus causing a concentration of potential toward the line end and resulting in successive breakdown, beginning at the line end.

In Fig. 6 the complete gap unit is shown. Small resistance rods on the bottom of the porcelain ring control the resistance distribution. The shunt capacitances are obtained from a series of depressions in which the springs rest in the bottom porcelain housing which is metal-coated on the under side and in the depressions. Thus the container itself supplies the necessary capacitance, while the springs make the connections from gaps to the capacitances and also serve as mechanical supports for the gap structure. Wet-process porcelain is used. Since it is only necessary that the resistance be of low enough value to compensate at normal frequency for stray capacitances and the capacitance purposely introduced, the normal current flow is of the order of microamperes.

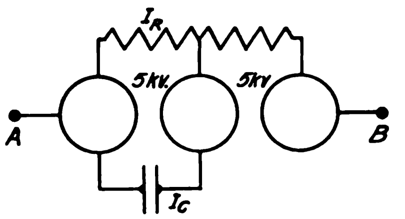


Fig. 4. Gap Arrangement to Give Impulse Ratio Less Than One, 60-cycle Breakdown, 10-kv. Crest
Impulse breakdown 5.6 kv. Impulse ratio 0.56.

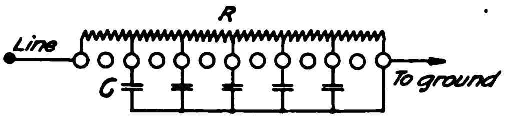


Fig. 5. Schematic Design of 11.5-kv. Gap Unit for Thyrite Arrester Unit

The test results on this gap have been most interesting, and have checked estimated performance within a few per cent. A curve is given in Fig. 7 showing the effect on the gap spark potential of changing the rate of potential rise. The curve shows that the spark potential at one microsecond to breakdown is only 20 per cent above the 60-cycle spark potential and is practically constant within the range of wave fronts met in service. From a consideration of the principles outlined in connection with Fig. 4, one would expect that when the resistance current becomes negligible in comparison with the capacity current the spark potential would reach and maintain a certain low value, less than the 60-cycle value. However, in actual gap design a new factor enters. This is the individual gap impulse ratio, which becomes larger as the front becomes steeper. The overall performance of this gap structure is considered as being very satisfactory. It is possible to have a fairly high 60-cycle breakdown and still keep the impulse breakdown low. When calculating Thyrite arrester performance the curve given in Fig. 7 is to be used for the gap breakdown.

For use in calculating arrester performance, arrester volt-ampere curves for Thyrite arresters rated 46 kv. to 230 kv. are given in Fig. 8. The 46-kv. arrester consists of four 11.5-kv. units, while the 230-kv. arrester is composed of 20 such units. Similar curves can be easily drawn for any number of units, since the voltage at a given current is directly proportional to the number of units.

Calculation of Thyrite Arrester Performance

As an example the first case to be considered here is that of an arrester at the end of a transmission line having an equivalent surge impedance per conductor equal to Z_1. Equation (5), given at the beginning of this article, applies to this condition. Thus if Z_1 is known or assumed, and the relation between E_A and I_A is known, it is possible to determine a value of E_A for each value of the incoming wave E_1. The traveling wave potential out on the line is E_1, while $2E_1$ is the potential at the end of the line if no arrester is present.

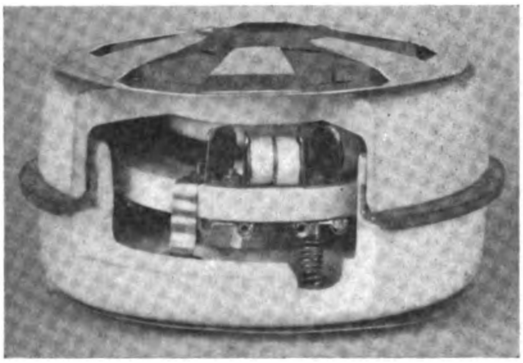


Fig. 6. Standard Unit of Thyrite Arrester, Cut Open to Show Internal Construction

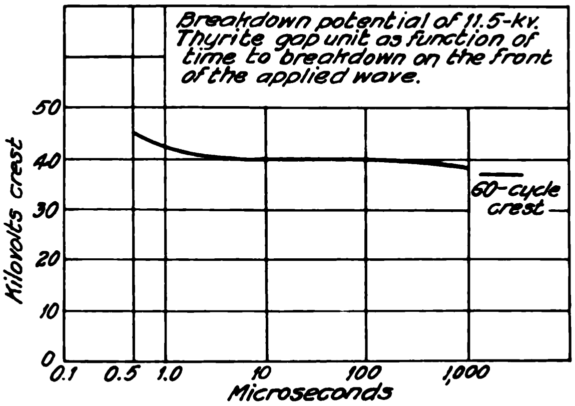


Fig. 7. Voltage Breakdown Characteristic of 11.5-kv. Thyrite Arrester Gap Unit

The application of Equation (5) is conveniently carried out graphically, as shown in Fig. 9. Here the abscissas represent both time in microseconds and current in amperes; the ordinates for both are kilovolts. At the left is plotted the wave $2E_1$ which would have appeared at the end of the line had the arrester not been present. This wave is assumed to rise at the rate of 100 kv. per microsecond per 11.5-kv. unit until arrester breakdown, which is at the rate of 1,000 kv. per microsecond since the arrester chosen for calculation is rated 115 kv. and will have ten 11.5 kv. units in series. After arrester breakdown, which is at 430 kv., the original wave ($2E_1$) is continued as a dotted curve. This wave reaches its crest of 1,000 kv. in about 1.5 microseconds, then decaying to half value in 20 microseconds. Such a wave might well be designated a 1.5-20 wave having a crest of 1,000 kv.

find a point on the arrester volt-time curve to correspond to the points A and A' on the wave at the end of the line without the arrester, project horizontally as indicated by the dotted line meeting the curve $E_A+Z_1I_A$ at the point B. The current corresponding to this point is about 730 amp., which will be the current flowing at times corresponding to A and A', or 0.96 and 12 microseconds respectively. The

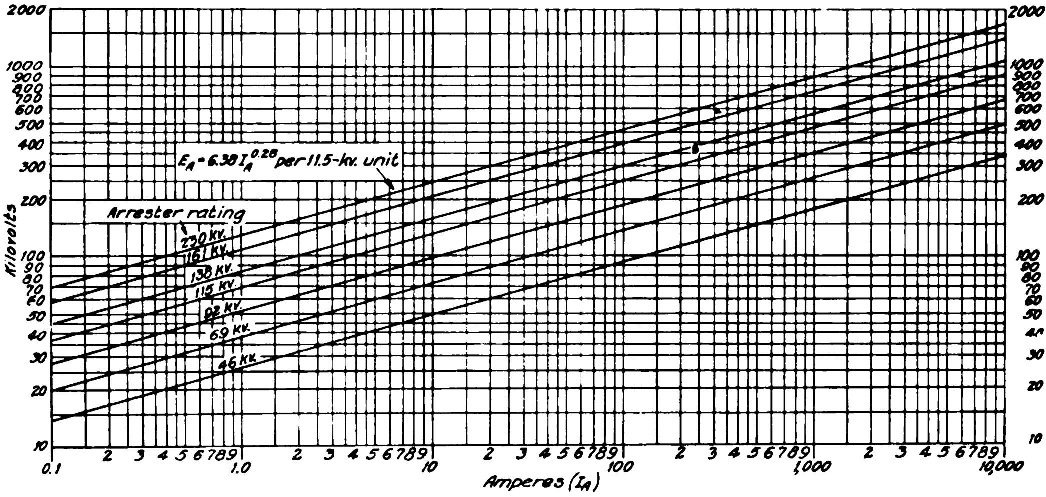


Fig. 8. Volt-ampere Curves of Thyrite Arresters for Grounded-neutral Service

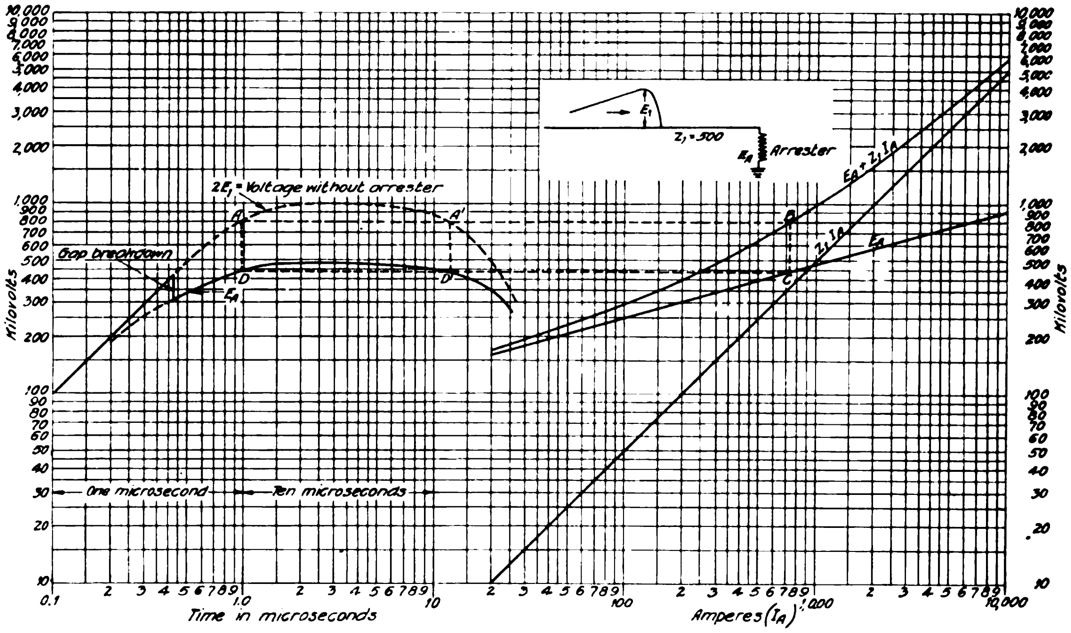


Fig. 9. Calculation of Thyrite Arrester Performance for Grounded-neutral Circuit (115-kv. Thyrite Arrester at the End of the Line)

At the right of Fig. 9 is plotted the volt-ampere curve for a 115-kv. arrester for grounded neutral circuits taken from Fig. 8. This curve is marked E_A. The equivalent surge impedance Z_1 is assumed to be 500 ohms, and Z_1I_A is plotted for various values of I_A. For different values of current the ordinates of the E_A and Z_1I_A curves are added, giving the curve marked $E_A+Z_1I_A$. From Equation (5) the ordinates of this curve are equal to $2E_1$. Thus for each value of E_A we have the corresponding value of $2E_1$. To

arrester potential corresponding to 730 amp. is found to be 440 kv. at the point C. This potential may be plotted at points D and D'. In this manner the complete volt-time curve for any assumed impulse may be obtained. By plotting the various values of current as at BC against the time as A and A' an ampere-time curve may be obtained. From Fig. 7 the arrester gap breakdown is obtained. The arrester volt-time curve is the applied wave up to arrester breakdown after which the curve is determined by the IR characteristic and the surge impedance of the line. It is not necessary to plot the volt-time curves on the log-log paper, as they can be plotted independently on coördinate paper with uniform scales, using values from the volt-ampere curves.

In Fig. 10 the performance of the arrester is shown in the form of volt-time, ampere-time, and volt-ampere curves, all plotted in rectangular coördinates. The arrester volt-time and ampere-time curves were based on the volt-ampere curves shown in Fig. 9.

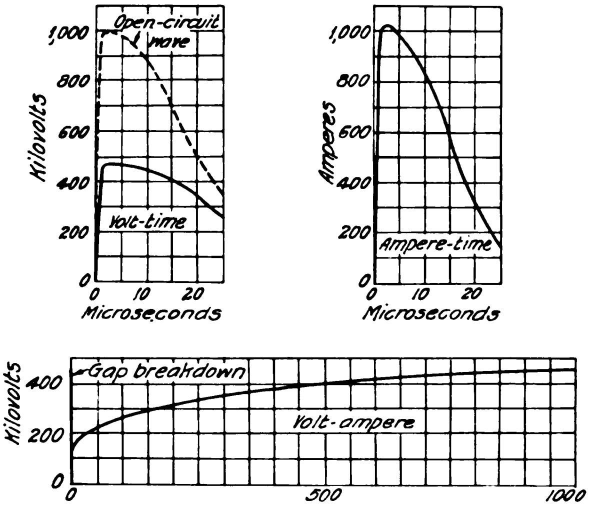


Fig. 10. Thyrite Arrester Performance Curves Obtained from Fig. 8

Other Circuit Conditions

The same method of calculation will apply for circuit conditions other than the arrester at the end of the line.

If two incoming circuits on the same towers discharge through the same arrester, the equivalent surge impedance of the two conductors which discharge in parallel into the same pole of the arrester must be used. If the individual surge impedances were each 500 ohms, then Z_1 of Equation (5) would be 250 ohms. Thus 250 I_A would be plotted instead of 500 I_A and the method of Fig. 9 followed.

For a surge impedance beyond the arrester, as Z^2 in Fig. 1, a very slight change in procedure is necessary. In this case Z_2 is to be expressed in terms of Z_1 as nZ_1. Thus instead of having Equation (5), *viz.*, $E_A + Z_1 I_A = 2\ E_1$, we have Equation (7), or

$$\left(1-\frac{1}{n}\right) E_A + Z_1 I_A = 2E_1$$

When determining the arrester performance for this condition, E_A and $Z_1 I_A$ are plotted as in Fig. 9. It is convenient to plot a new curve of $\left(1+\frac{1}{n}\right) E_A$ parallel to E_A and then add $Z_1 I_A$ to this curve to obtain a curve whose ordinates correspond to the values of $2E_1$ as in Equation (7).

When the curve of E_A is not a straight line, it is more convenient to obtain the curve of $\left(1+\frac{1}{n}\right) E_A + Z_1 I_A$ directly by calculation of each individual point rather than by plotting the intermediate curve of $\left(1+\frac{1}{n}\right) E_A$.

Thus a value of E_A and of I_A are obtained corresponding to each value of $2E_1$. If a curve of $2E_1$ as a function of time is given we can therefore plot corresponding volt-time and ampere-time curves for the arrester.

Thus calculations of arrester performance can be made for any assumed line connections. Cathode-ray oscillograms of artificial traveling waves taken on transmission lines with and without the Thyrite arrester show very close agreement with the calculated values. It thus becomes possible to take characteristics obtained in the laboratory and determine what would have been obtained if the test had actually been made on the transmission line. It cannot be emphasized too strongly, however, that one must be sure that the arrester volt-ampere curve is either unaffected by rates of voltage and current rise, and the magnitude and duration of the current, or else that curves showing the effect of these variables are provided, otherwise the calculated results cannot be used with assurance.

Special Conditions of Protection

Some classes of apparatus require not only that the potential be reduced to a safe value, but also that the wave front be modified so that turn-to-turn stresses may be reduced. For such an application a number of arrangements have been considered. A combination of capacitor and arrester seems to offer a satisfactory solution. It may not be always possible to use capacitors on account of inductive interference or for other reasons, while in the higher voltages, perhaps above 33 kv., the necessary large capacitance is quite expensive at present, although changes in the art may remove this limitation at a later date. The advantages of large protective capacitors have long been appreciated, but their expense has precluded their use except in special cases.

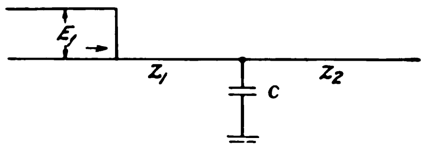


Fig. 11. Capacitor Connected to Transmission Line; General Case

Fig. 11 is a schematic diagram of the general case of a traveling wave E_1 approaching a line-to-ground capacitor C over an equivalent surge impedance

Z_1 and passing to an outgoing surge impedance Z_2. The equations for this circuit can be obtained in a way similar to the foregoing, as applied to the arrester. In either case an equivalent circuit can be used, considering the surge impedances as concentrated resistances and applying twice the given traveling wave voltage. Both methods lead to the same differential equations and therefore give the same equation for E_c. Considering Z_2 as a resistance in parallel with C, the equation involving E_c is:

$$Z_1 (I_c + I_2) + E_c = 2E_1 \tag{9}$$

but

$$I_2 = \frac{E_c}{Z_2} \tag{10}$$

$$I_c = C\frac{dE_c}{dt} \tag{11}$$

$$\therefore \quad Z_1 C\frac{dE_c}{dt} + \left(1 + \frac{Z_1}{Z_2}\right) E_c = 2E_1 \tag{12}$$

$$E_c = E_1 \frac{2}{Z_1 C}\,\frac{1}{p+\alpha} \qquad \alpha = \frac{Z_1 + Z_2}{Z_1 Z_2 C} \tag{13}$$

$$E_c = E\,\frac{2Z_2}{Z_1 + Z_2}\left[1 - \epsilon^{-\alpha t}\right] \tag{14}$$

The foregoing equation applies to the case of a rectangular wave, E_1. The solution for a sloping wave follows in a simple way when the incoming wave voltage varies according to any of the common time functions or the sum of several such functions. It happens that the sloping waves occurring in service can usually be represented by some expression such as

$$E = E\left(\epsilon^{-At} + \epsilon^{-Bt}\right) \tag{15}$$

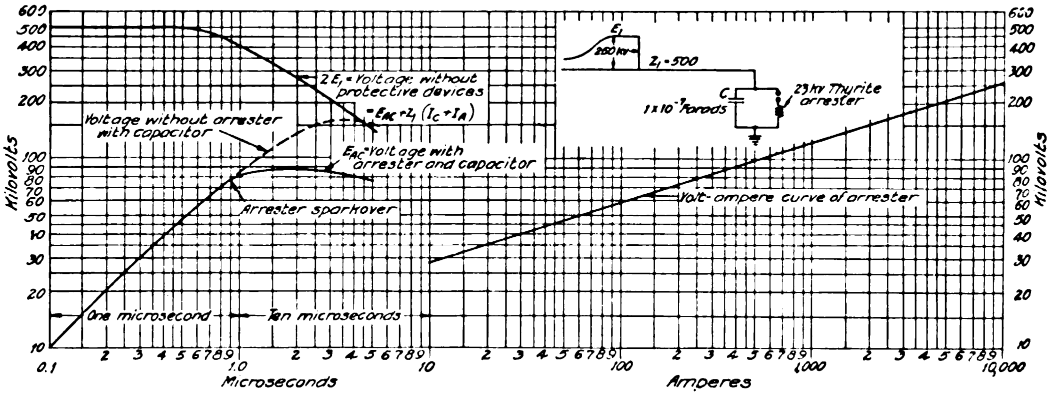


Fig. 13. Curves for the Calculation of Performance of the Arrester-capacitor Combination

The capacitor voltage is then

$$E = 2E\left[\frac{1-\epsilon^{-(A+\alpha)t}}{Z_1+Z_2+AZ_1C}\,\epsilon^{-At} + \frac{1-\epsilon^{-(B+\alpha)t}}{Z_1+Z_2+BZ_1C}\,\epsilon^{-Bt}\right] \tag{16}$$

In Fig. 12 is shown the volt-time curves of two capacitors, one of 0.03 mf. capacity and the other of 0.3 mf. The curves are plotted in terms of percent of E_1, the traveling wave potential. A rectangular incoming wave is assumed and a surge impedance of 500 ohms. These curves show that a relatively large capacitance is needed if a great reduction in potential is to be effected, unless the wave is very short. An arrester in combination with the capacitor insures that, no matter how long the wave may be, the potential will not exceed that allowed by the arrester, while the capacitance can be chosen of such magnitude that turn-to-turn stresses produced by the rising front of the voltage wave are reduced to safe values. This combination of arrester and capacitor is a good illustration of the general principle of composite protective equipment which is particularly adapted to the protection of rotating machinery directly connected to overhead transmission lines and thus exposed to the effects of lightning.

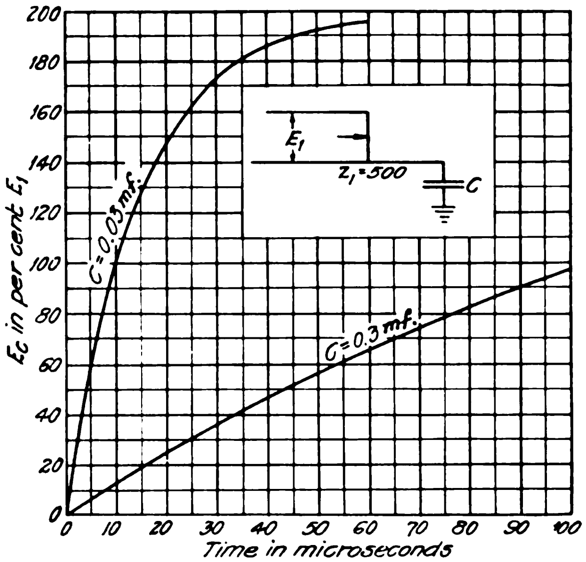


Fig. 12. Volt-time Curve of Capacitor Connected to a Transmission Line

The case of a gap-resistance type of arrester in shunt with a capacitor is easily calculated if the arrester resistance is constant. The equations are somewhat similar to those already given, since the arrester resistance and the surge impedance Z_2 are in parallel and so the arrester resistance has an effect similar to that of changing Z_2. However, the resistance of modern arresters is not a constant but decreases with increasing voltage and current. Except in one or two special cases, the equations of circuits involving such variable resistance are not in a form which can be readily handled. It is possible to take the equations for a constant resistance and use a step-by-step process to approximate the relationships existing with the variable resistance. In general, the simplest method of handling this problem is to assume a group of curves for voltage across the arrester-capacitor combination and then calculate a group of the corresponding curves for $2E_1$, where E_1 is the incoming voltage wave. This can be done by methods similar to those just given. When there is an arrester in parallel with the capacitor of Fig. 12, a current I_A is added to the other currents and Equation (12) then becomes

$$Z_1C\frac{dE_A}{dt}+\left(1+\frac{Z_1}{Z_2}\right)E_A+Z_1I_A=2E_1 \qquad (17)$$

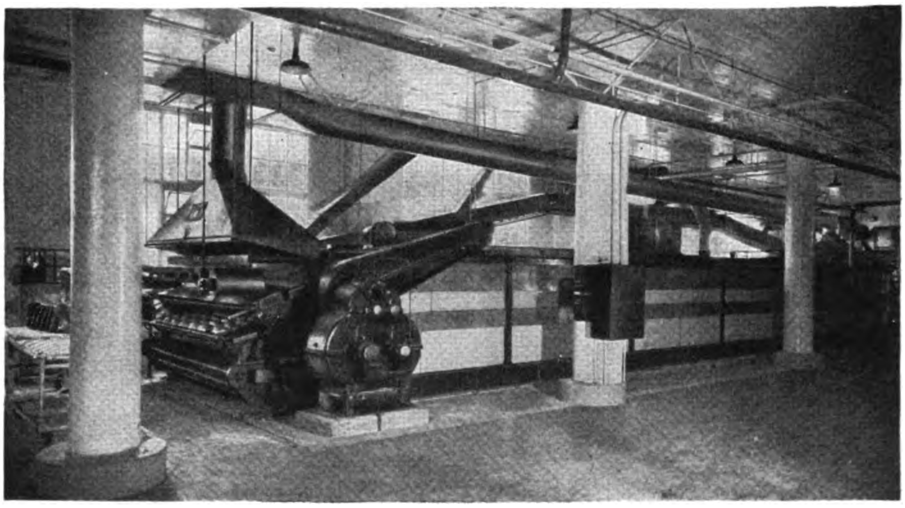
It is evident from this equation that any curve for E_A enables us to calculate a corresponding curve for $2E_1$. Values of I_A are taken from the volt-ampere curve for the given arrester. Values of $\frac{dE_{AC}}{dt}$ can be obtained graphically from the curve for E_c or mathematically from its equation. Fig. 13 shows a set of such curves. The curves for E_{AC} and $2E_1$ are quickly and easily drawn; and these are the important curves. If it is desired to draw the curve for the capacitor without the arrester, considerably more work is involved as it is necessary to determine an approximate equation for $2E_1$ and then calculate the curve for capacitor voltage. In case a curve for $2E_1$ is given, a group of curves for E_{AC} can be drawn and the corresponding curves for $2E_1$ obtained graphically. In this manner a curve for $2E_1$ can be obtained which approximates the given curve.

Conclusions

The Thyrite arrester characteristics are particularly adapted to the calculation of arrester performance because the volt-ampere curve has no loop and therefore is fixed, having only one value of voltage for each value of current. The graphical methods which have been described permit the arrester performance to be determined in a very simple way with a minimum of mathematical calculations.

The writers wish to acknowledge their appreciation of the contributions made by those who have assisted in the design and construction of the equipment used, and to those who have aided in the preparation of material in this article.

Electric Ovens for Better Baking



In baking, as in other industrial processes, the desirability of electric heat appears in a greater excellence of product, more effective control, and better working conditions

Characteristics of the New General Electric Sunlamp

By W. E. FORSYTHE, B. T. BARNES and M. A. EASLEY
Lamp Development Laboratory, General Electric Company
Nela Park, Cleveland, Ohio

In earlier articles published in the REVIEW, *notably "Simulating Sunlight," in the February issue, and that by Gordon and Benford in the May issue, the G-E Sunlamp has been considered with regard to its construction and to the nature of the rays it emits. Here, its characteristics are considered in further detail, chiefly with respect to the production of its radiation.*—EDITOR

THE source of radiation of the new Sunlamp is a 300-watt, alternating-current tungsten-mercury arc, *i.e.*, it is a mercury arc between tungsten electrodes with the general arrangement of the electrodes and filament as shown in Fig. 1. This source is called the Type S-1 lamp. The data given in this article were obtained from Type S-1 lamps designed and manufactured in the Lamp Development Laboratory at Nela Park. All the data given in the form of tables and curves refer to the lamp alone and not to the lamp in a reflector unless otherwise noted. In later paragraphs of the article and in Figs. 14 and 15 are given some data on the complete unit, *i.e.*, the lamp in the regular reflector and with the accessories which altogether constitute the Sunlamp.

Besides its being an efficient source of ultra-violet radiation, the Type S-1 lamp has the distinguishing characteristic of simplicity of starting and operating. All that it is necessary to do is to close a switch just as with an incandescent lamp. The lamp conditions are set up so that the arc will start easily. In the bulb there are several centimeters Hg pressure of very pure argon, which has a low arcing potential. In addition, there is the pressure of the mercury vapor that results from a small amount of mercury within the lamp.

When the lamp is first turned on, the filament in parallel with the arc is heated to a very high temperature, making it a good source of electrons. The dimensions of the filament and the characteristics of the transformer are such that initially there is a current of 9½ amp. through the filament and a potential of about 30 volts across it. This voltage is sufficient to start an arc under conditions as they exist in the lamp. Electrons travel between the upper ends of the filament, or more probably, from each end of the filament to the opposite electrode since that would give a shorter path with the same voltage drop. Since these electrons fall through sufficient potential difference to produce ionization of the argon present in the bulb, an arc is started. The bombardment of the electrodes makes them hot enough to furnish electrons for the arc. As soon as this happens the arc moves up between the electrodes and no longer plays between the upper ends of the filament. When the arc is established between the electrodes the lamp carries about 30 amp. and its voltage drops to about 10 volts. This change in voltage and current from the starting conditions to the operating conditions of the lamp is taken care of in the design of the transformer. When the lamp is first turned on, the temperature of the filament may be more than 3000 deg. K. but after the arc starts between the electrodes its temperature drops to 2200 or 2300 deg. K.

A curve showing the voltage-current characteristic of the lamp is given in Fig. 2. The section *ODA* of the curve, which gives the volt-ampere relation for the tungsten filament, is followed when the arc is not operating. The line *CBP* gives the volt-ampere relation for the lamp after the arc has struck. Transition from one stage of operation to the other, when the arc strikes or breaks, is quite rapid. The dotted lines *AB* and *CD* probably do not represent the volt-ampere characteristic during the transition periods—*AB* is merely a straight line connecting the point *A* which gives the voltage and current just before the arc strikes to the point *B* showing the values noted after the arc has stabilized, and *CD* connects the corresponding points when the arc breaks.

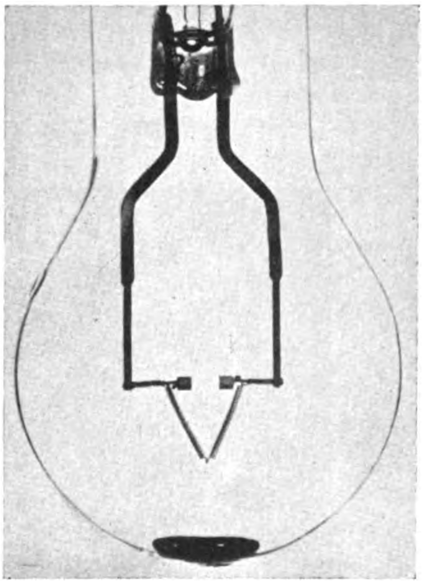


Fig. 1. General Arrangement of Electrodes and Filament in the Type S-1 Lamp

In Fig. 3 are shown spectra of the arc stream obtained immediately after the lamp is turned on (Spectrum 1), and also after the arc has been established and has reached a steady state (Spectrum 2). For comparison there is given a spectrum of the quartz mercury arc. In the spectrum taken immediately after the lamp is turned on there are a number of lines that are not shown in the arc stream after the lamp has reached a steady state. These lines, for the most part, can be identified as lines from the rare gases present in the bulb.

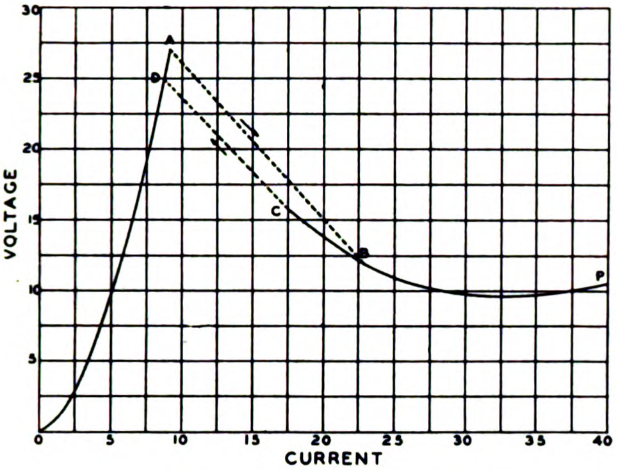


Fig. 2. Volt-ampere Curve for Type S-1 Lamp

Section *ODA:* Tungsten filament characteristic followed when arc is not operating. Section *PBC:* Arc characteristic. Arc starts when point *A* is reached, passing quickly to the operating condition indicated by point *B*. Arc does not break till point *C* is reached. Lamp voltage and current change at once to those given by point *D*.

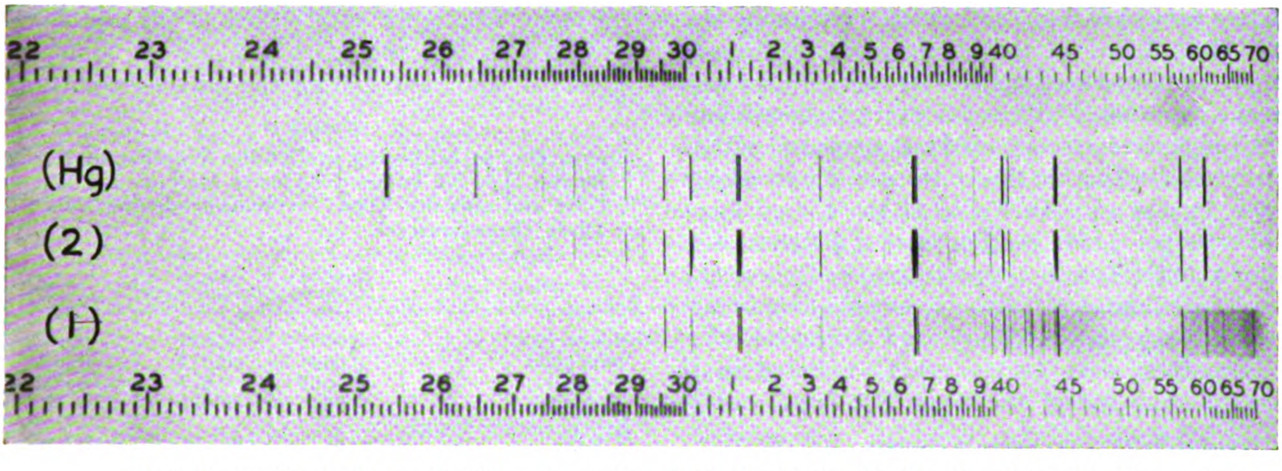


Fig. 3. Spectra of the Arc Stream of the Type S-1 Lamp Immediately After Starting (Spectrum 1), and After Reaching a Steady State (Spectrum 2). The spectrum of the mercury arc is given also for comparison

Since the Type S-1 lamp was intended as a source of ultra-violet radiation, it was necessary to use a special glass for the bulb since ordinary glass transmits practically no energy for wavelengths shorter than about 3100Å. A fairly high transmission for the radiation between wavelengths 2900 and 3100Å is considered especially desirable. A special glass has been developed which has been found very satisfactory in this respect. A curve showing the transmission of a sample of this glass 1 mm. thick is given in Fig. 4.

The radiation from this lamp can be very conveniently separated into two parts: First, that from the heated tungsten; and, second, that from the mercury arc. The radiation from the heated tungsten gives a continuous spectrum and that from the mercury arc is made up of many lines of different wavelengths. By far the greater part of the energy radiated in the region between 2800 and 3200Å by the Type S-1 lamp comes from the mercury arc. Probably only about one per cent of the energy in this region comes from the incandescent tungsten.

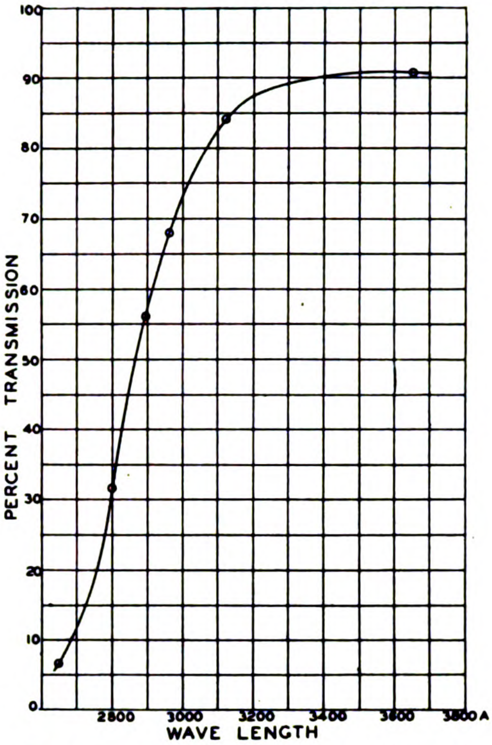


Fig. 4. Transmission Curve for a 1-mm. Thick Piece of Special Glass Such as is Used for the Bulb of the Type S-1 Lamp

The easiest way to study the extent of the ultraviolet is to take a photograph of the spectrum. It is also possible to measure approximately the relative intensity of different wavelength regions in the spectra of different sources by comparing the density of their spectrograms. This, however, is very difficult and time-consuming.

Using a spectrometer to separate the radiation into its component wavelengths and a very sensitive thermopile connected to a sensitive galvanometer as the receiving instrument, it is possible to measure the intensity of the stronger lines in that part of the spectrum which is considered to have therapeutic value. An advantage of this method is that it gives directly the relative intensity of different lines from which a comparison can be made of the radiation of different lamps. The average value obtained for the relative intensity of the more important groups of lines in the ultra-violet portion of the spectrum of the Type S-1 lamp using a spectrometer with a thermopile as the receiver is given in Table I.

Multiplying the intensity of the different lines by the values given by Hausser and Vahle (1) for the relative effectiveness of ultra-violet energy of different wavelengths in producing erythema (Fig. 5), a measure is obtained of the relative amount of erythema which will be produced by radiation of each wavelength. The results, expressed in per cent of the total amount of erythema which would be produced with a suitable exposure, are given by the last line of Table I.

In the Research Laboratory at Schenectady, Benford has measured the energy flux in absolute units in the various parts of the spectrum in the Type S-1 lamp. According to his measurements about 0.8 per cent of its input energy is radiated below 3200Å. Making use of the data obtained by Benford, the relative values given in Table I can be reduced to absolute values. From the absolute intensity of the radiation in the ultra-violet region from the Type S-1 lamp, the energy radiated within definite wavelength limits in this region can be computed and compared with the energy radiated within the corresponding wavelength region by the sun. In Table II the energy flux in milliwatts per square centimeter at a distance of one meter from the Type S-1 lamp is given for three definite wavelength limits and for comparison like data from the sun (2) and the quartz-mercury arc (3) are included.

Using these data on the energy radiated in the ultra-violet region of the Type S-1 lamp and the values given by Hausser and Vahle for the relative effectiveness of ultra-violet energy of different wavelengths for producing erythema, the erythema-producing effect of the radiation of the Type S-1 lamp was calculated for a distance of one meter from the lamp. Taking the effectiveness of the sun directly overhead as 100, this gives a figure of 50 for the Type S-1 lamp, and 280 for the quartz-mercury arc.

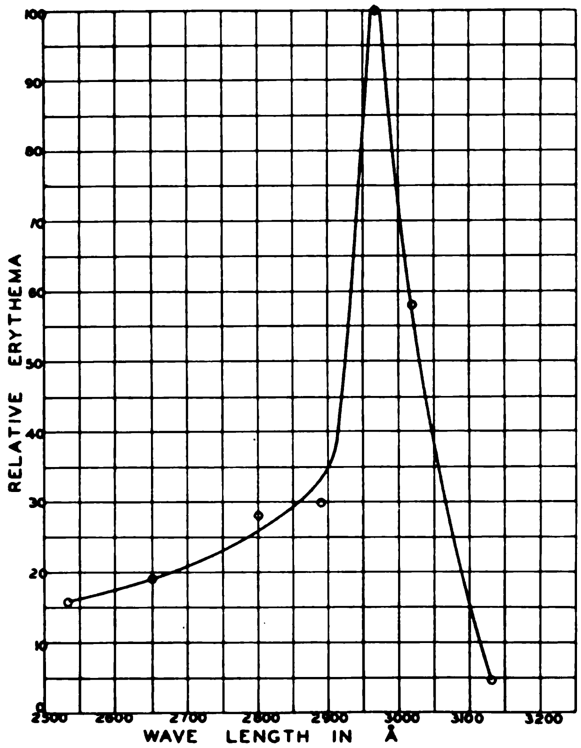


Fig. 5. Relative Effectiveness of Ultra-violet Light of Different Wavelengths in Producing Erythema as Given by Hausser and Vahle.(1) Effectiveness is taken as proportional to the reciprocal of the exposure (energy × time) necessary to produce a faint reddening of the skin

TABLE II

Energy Flux in Milliwatts in Definite Wavelength Regions for the Type S-1 Lamp, the Quartz Mercury Arc and the Sun; and also the Total Erythema-producing Effect for These Three Sources

Wavelength Limits	Type S-1 Lamps*	Quartz Mercury Arc*†	Sun‡
Below 2800	0.0002	0.037	0.0
2900-3000	0.0021	0.012	0.00064
2800-3100	0.0067	0.034	0.024
2900-3200	0.021	0.070	0.14
Erythema Producing Effect	50.00	280.00	100.00

* At a distance of one meter from the lamp.
† At 3.75 amp.; 72 volts on lamp
‡ Sun directly overhead.

TABLE I

RELATIVE INTENSITY AND ERYTHEMA-PRODUCING EFFECT OF SOME ULTRA-VIOLET LINES FROM THE TYPE S-1 LAMP

Wavelength (Å)...................	3650–63	3342	3125–32	3024	2967	2925	2894	2804	2642–55
	PER CENT								
Relative Intensity.................	192	12	100	28	15	1	3	3	1.5
Per Cent of Total Erythema Produced			12	43	39	1	2	2	1

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(1) *Strahlenther 18*, p. 41, 1922.

(2) "Ultra-violet Radiation from the Sun and from Heated Tungsten," by Dr. W. E. Forsythe and Frances Christison, General Electric Review, Dec., 1929, p. 662-667.

(3) Benford—unpublished data.
Anderson, Fraser and Bird: *Journal of Optical Society* 17, 460, Dec., 1928.

A Type S-1 lamp consuming 310 watts dissipates this energy about as given in Table III.

Some of these figures, of course, are estimates based on measurements of this and other types of lamps. According to measurements made with voltage pick-off terminals, there is about one volt drop in the leads of this lamp when it is carrying 30 amp. In other lamps of this wattage the gas loss amounts to eight or ten per cent and the end loss from two to three per cent. It is assumed that these figures are approximately correct for the Type S-1 lamp. The filament carries about 4½ amp. when the arc is running. The mercury arc in the lamp gives about 900 lumens. If the arc is furnishing light at about 18 lumens per watt, about 50 watts are consumed by it. The average temperature of the arc terminals is about 3160 deg. K. and the average temperature of the filament is about 2200 deg. K. At the temperature of the filament there is less than 0.1 per cent of the energy radiated for wavelengths shorter than 4000Å and about three per cent in the visible spectrum. On the other hand, at the average temperature of the arc terminals there is about 0.6 per cent of the energy radiated in the portion of the spectrum below 4000Å, and about 18.6 per cent of the energy radiated within the visible spectrum. According to Benford's measurements, there is about 0.8 per cent of the input energy radiated by the Type S-1 lamp below 3200Å. From the relative intensity of the different lines in the ultra-violet portion of the spectrum the ratio of the energy between 2800 and 3200Å to the total energy from the arc within the ultra-violet portion of the spectrum can be calculated. This shows that about 2.0 per cent of the energy of the Type S-1 lamp is radiated by the arc alone within the ultra-violet portion of the spectrum. The results of this computation agree with data obtained by Benford who found that the radiation below 4000Å from the arc amounted to 2.0 per cent of the total input of the lamp. The visible radiation from the arc alone is also 2.0 per cent of the total input energy, according to his measurements. Table IV contains a summary of the radiation in the different parts of the spectrum, as thus arrived at.

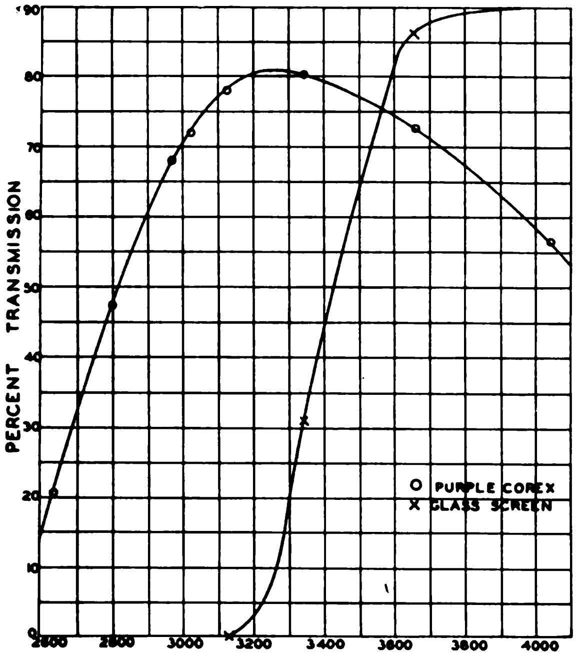

Fig. 6. Spectral Transmission of Purple Corex and a Glass Screen

TABLE III
DISSIPATION OF ENERGY FROM A TYPE S-1 LAMP

Leads	30	Watts
Gas Loss	30	"
End Losses	10	"
Filament	45	"
Mercury Arc	50	"
Arc Terminals	145	"

TABLE IV
RADIATION IN THE DIFFERENT PARTS OF THE SPECTRUM

	PER CENT		ENERGY FLUX IN MILLIWATTS	
	Ultra-violet	Visible	Ultra-violet	Visible
Filament	0	3.0	0	1.4
Arc Terminals	0.6	18.6	0.9	27.0
Mercury Vapor	2.0	2.0	6.2	6.2
			7.1	34.6

The figures in Tables III and IV show that 2.3 per cent of the input is radiated for wavelengths below 4000Å and 11.1 per cent for the visible spectrum that is between 4000 and 7600Å.

Nothing has been said concerning the amount of energy radiated in the infra-red portion of the spectrum. The reason for this is that in this lamp a considerable portion of the energy is carried away by the convection and conduction of the air. The amount of this would be quite difficult to estimate, but from the figures given for the gas loss, energy spent in the leads, and end losses, it is evident that it might amount to several per cent of the input.

The second method used to measure the ultra-violet radiation consists of a photoelectric tube with a quartz bulb connected to a sensitive galvanometer as the measuring instrument, and screens to separate the ultra-violet radiation below 3200Å from the other radiation from the lamp. A sodium photoelectric tube in a quartz bulb can be so constructed as to be quite sensitive to radiation in the neighborhood of 3000Å. These sodium tubes have a rather high sensitivity for long wavelength ultra-violet radiation and also a considerable sensitivity for short visible radiation. It is thus necessary to in some way limit this long wavelength sensitivity. The Corning Glass Company makes a purple Corex glass that has a rather high transmission (Fig. 6) in the ultra-violet region around 3000Å and a somewhat lower transmission in the short wavelength visible spectrum. The sodium photoelectric tube with such a screen in front of the window makes a very satisfactory measuring instrument for the short ultra-violet radiation. If this combination of photoelectric tube and purple Corex glass is exposed directly to the radiation from the Type S-1 lamp, the reading obtained on the galvanometer is a measure in arbitrary units of all the ultra-violet energy transmitted by the bulb of the lamp and the purple corex glass screen.

Now it just happens that there are no very strong lines in the spectrum of the mercury arc between about 3130 and 3650Å and it is also a fortunate coincidence that the transmission of ordinary glass (Fig. 6) is quite large for the radiation of the mercury arc longer than 3600Å and almost zero for the radiation at 3130Å. If another reading is taken with a piece of ordinary glass between this receiver and the source, a measure will be obtained of the ultra-violet energy from this lamp of wavelengths longer than about 3200Å that is transmitted by this second screen. If this reading is corrected for the transmission of the glass screen, which can be obtained in a number of ways, a value is obtained in the same arbitrary units for the ultra-violet radiation of wavelengths longer than 3200Å. Subtracting this value from the first reading obtained gives a measure of the ultra-violet energy of wavelengths shorter than 3200Å. The limit was set at 3200Å so as to include the group of lines at about 3130Å since there is practically no radiation from the mercury arc between 3130 and 3340Å.

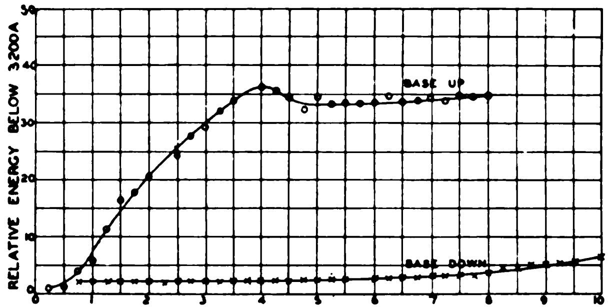

Fig. 7. The Variation of Ultra-violet Radiation Below 3200Å Immediately After the Lamp is Turned On. The upper curve is for the lamp in the normal position with the base up and the lower curve is for the base down. (115 volts applied to the primary of the transformer)

The lumen output of the Type S-1 lamp was measured by comparing it in a spherical photometer with an ordinary 500-watt gas-filled tungsten standard lamp. The light is made up of two parts, that from the incandescent tungsten and that from the mercury arc. The light from the mercury arc is composed of a number of lines distributed in the yellow, green, and blue portions of the visible spectrum. There are no lines of any appreciable strength in the red end of the spectrum. Thus, if the light intensity of the Type S-1 lamp in the red portion of the spectrum is measured, the results obtained will correspond to the radiation from the incandescent tungsten. The results of some measurements of temperature of the arc terminals and filament of the Type S-1 lamp showed that its average color temperature corresponded to about that of the ordinary 500-watt gas-filled tungsten lamp. Thus, by comparing the light intensity of a standard 500-watt lamp and a Type S-1 lamp using a red glass in the eyepiece of the photometer, results were obtained that corresponded to the relative amount of light radiated by the 500-watt tungsten standard lamp and the incandescent tungsten of the Type S-1 lamp. From these measurements the percentage of the light from the mercury arc was calculated and such values are given in Table V.

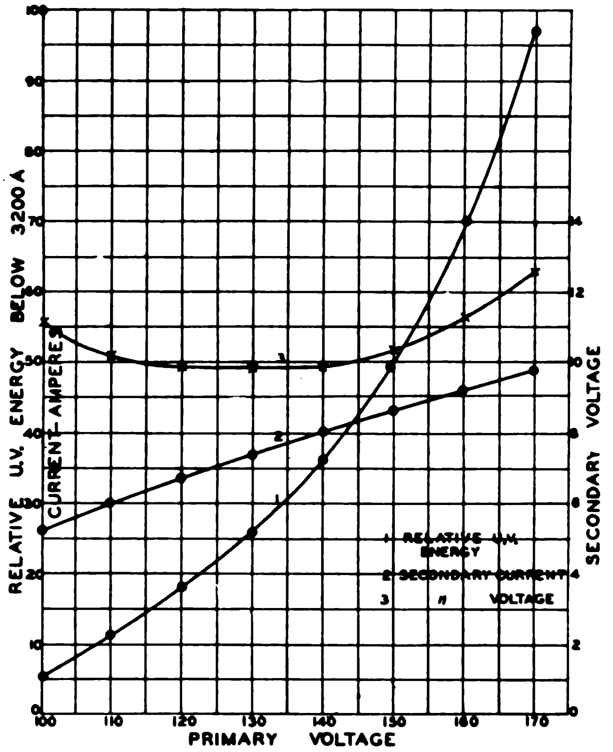

Fig. 8. Variation of the Ultra-violet Below 3200A as a Function of the Voltage applied to the Primary of the Transformer (Curve *1*). In Curve *2* is shown the variation of the secondary current; and in Curve *3* is shown the variation of the secondary voltage under the same conditions

TABLE V

SOME CHARACTERISTICS OF THE AVERAGE TYPE S-1 LAMP

Distance between electrodes	5.4 mm.
Current	30.6 amp.
Voltage	9.8 volts
Light output	6050 lumens
Lamp efficiency	19.4 lumens per watt
Percentage of light from the mercury arc	16.6
Light from the filament	100 lumens
Maximum temperature of the electrodes	3260 deg. K.
Maximum temperature of the filament	2330 deg. K.
Temperature of mercury in lamp	285 deg. C.
Pressure of mercury vapor within the lamp	177 mm. Hg.

The amount of light radiated by the filament of the Type S-1 lamp was determined by starting the lamp at a low voltage and slowly increasing it to the operating voltage and then measuring the light output of the lamp. Of course, if the lamp is started in this way, the arc does not strike and the only light is that from the filament. The temperature distribution in the filament is quite different when operated in this manner than it is when the arc is operating since the arc heats the upper turns of the filament. Since the conditions under which the measurements were made were necessarily quite different from those when the arc is operating, the figure given in Table V for the amount of light from the filament may be slightly in error. This measurement shows that the filament takes about five amperes and gives about 100 lumens which is only about 1.7 per cent of the total light of the lamp.

The data given in Table V are thus the characteristics of this new tungsten-mercury arc. The results given in this table are the average obtained from the measurements of a great number of lamps. They show about how the average lamp would operate under normal conditions.

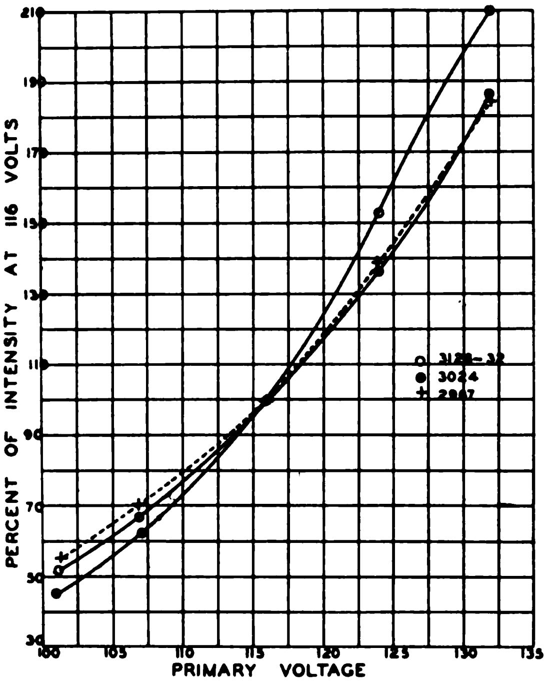

Fig. 9. Intensity *vs.* Primary Voltage Curves for the Ultra-violet Radiation at Three Different Wavelengths

As was mentioned in the introduction, the arc is started by ionization of the argon present in the bulb. Very soon the heat of the filament and the arc vaporizes some of the mercury and then the arc is carried chiefly by the mercury vapor. It takes some time for the ultra-violet radiation to reach a steady state since this will not occur until the temperature of the lamp becomes steady. The curve in Fig. 7 shows the ultra-violet radiation below 3200 Å as a function of the time after the lamp is turned on. The upper curve is for the lamp burning in its normal position; the lower is for the lamp burning with base down so that the mercury was not heated by the filament or arc.

In Fig. 8 is shown the ultra-violet radiation below 3200Å as a function of the voltage applied to the primary of the transformer. Here is shown also the variation of the current through the lamp and the voltage applied to the lamp as the primary voltage is changed. In Fig. 9 are shown the relative intensities of the three important lines in the ultra-violet region as functions of the voltage applied to the primary of the transformer. Data on these curves (Figs. 8 and 9) show that there is a very rapid increase in the ultra-violet energy, and especially in the lines at 3024Å from this lamp as the voltage applied to the primary of the transformer is increased.

The variation of the ultra-violet radiation below 3200Å in a horizontal plane through the electrodes as a lamp was rotated about a vertical axis is shown in Fig. 10. The points at 10 and 190 deg. represent the relative energy along a line passing through the center of the arc perpendicular to the plane of the leads, while the points at 100 and 280 deg. represent the relative energy along a line passing through both electrodes.

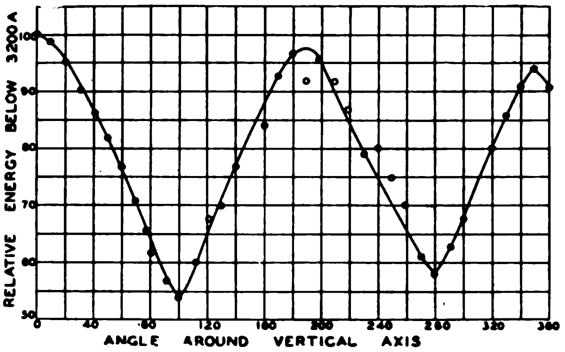

Fig. 10. Variation of the Ultra-violet Radiation Below 3200Å as the Lamp is Rotated Around a Vertical Axis. The 10-deg. and 190-deg. points show the relative energy in a line from the center of the arc perpendicular to the plane of the arc terminals with 115 volts applied to the primary of the transformer

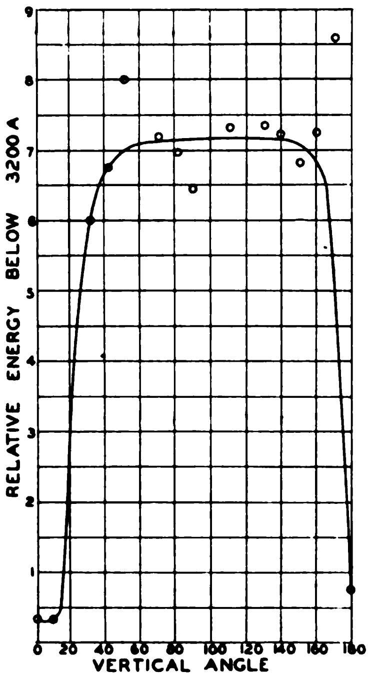

Fig. 11. Variation of Ultra-violet Radiation in a Vertical Plane Passing Through the Point Midway Between the Arc Terminals at Constant Distance from the Lamp. The zero position is directly under the lamp (115 volts applied to the primary of the transformer)

Fig. 11 shows the readings obtained as the photoelectric tube was rotated about a horizontal axis passing through the center of the arc. At zero degrees, where the tube was directly under the lamp, the mercury pool cut out practically all the radiation. As soon as the tube had passed beyond the shadow of the pool, the readings were approximately constant until the tube was directly above the base of the lamp.

The temperature of the mercury pool in Type S-1 lamps has been determined by means of a thermocouple threaded through a small tube sealed into the bulb. The junction of this thermocouple was located at the middle of the tube which was immersed in the mercury pool. It was found that for new lamps burning in the open with 115 volts on the primary of the transformer, the temperature of the mercury pool was ordinarily 270 deg. to 300 deg. C.

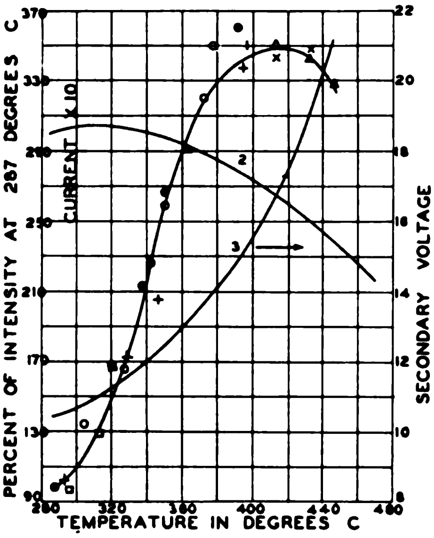

Fig. 12. In Curve *1* is Shown the Variation of the Ultra-violet Energy Below 3200Å as a Function of the Temperature of the Mercury; in Curve *2*, the Variation of the Secondary Current; and in Curve *3*, the Variation of the Voltage Across the Lamp. All taken with 115 volts applied to the primary of the transformer

By placing a small electric heater beneath one of these lamps provided with a thermocouple, the temperature of the mercury pool could be raised at will and the effect on the operation and output of the lamp studied. Fig. 12 shows the changes in lamp voltage, current and ultra-violet output below 3200 Å as measured with a photoelectric tube when the temperature of the mercury pool was increased and the primary voltage kept constant. Fig. 13 shows corresponding data on another lamp for the radiation at three different wavelengths measured with the spectrometer-thermopile set-up. The curve for the volt-ampere input of the lamp is included to indicate the rapid increase in the efficiency with which ultra-violet radiation is produced as the temperature is raised. The efficiency of the lamp in producing ultra-violet radiation increases somewhat faster than the square root of the mercury vapor pressure. The latter rises from 0.2 atmospheres at 279 deg. C. to approximately four atmospheres at 450 deg. C. Increased efficiency would be accompanied by a decrease in the life of the lamp. Just as in the case of incandescent lamps, operating conditions are determined by a proper consideration of both the efficiency and the life of the lamp.

During the life of the lamp the bulb blackens considerably more than is usually the case with incandescent lamps. This is probably due chiefly to water vapor driven out of the glass on account of the high bulb temperature. By a curious set of circumstances, this blackening usually causes an increase in ultra-violet output during life. The deposit, of course, reduces the transmission of the bulb for both ultra-violet and visible light. But it absorbs sufficient energy in the infra-red to raise the temperature of the bulb and the mercury pool considerably. The resulting increase in the ultra-violet output from the arc more than offsets the absorption of the black deposit. For example: Table VI gives data on one lamp with quite a large increase in both bulb temperature and ultra-violet output.

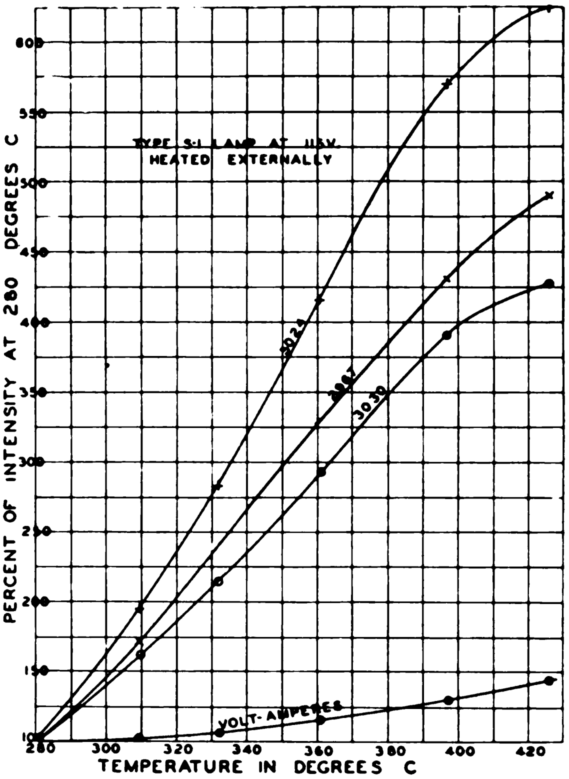

Fig. 13. Intensity *vs*. Temperature of the Mercury Pool Plotted for Three Different Wavelengths (115 volts applied to the primary of the transformer)

TABLE VI

Changes in Temperature of the Mercury Pool and the Ultra-violet Output of a Type S-1 Lamp During Life

Hours burned	0	43	88	131	166
Temperature of mercury pool in deg. C.	277	317	337	342	355
Ultra-violet below 3200 Å (Per cent of original)	(100)	123	193	155	150

During the first 88 hr. of burning, the temperature increase was quite marked and the ultra-violet output nearly doubled. With further burning there was not much rise in temperature, increased absorption being the chief effect of the blackening of the lamp. The increase in the ultra-violet from this lamp is unusually large. Other lamps showed about the same temperature rise but less increase in ultra-violet.

The data given in the foregoing tables and curves represent the characteristics of this new tungsten-mercury arc insofar as they have been studied. According to Hausser and Vahle's relation shown in Fig. 5, with equal amounts of energy, radiation at 2967 Å is nearly twice as effective in producing erythema as that at 3024 Å. In the radiation from Type S-1 lamps, the line at 2967 Å has about half as much energy as the group at 3024 Å. Hence, the radiation at each of those two wavelengths will be approximately equally effective in producing erythema. The radiation at all other wavelengths is much less effective.

The values that are here presented for the ultra-violet radiation show that this lamp radiated an amount of ultra-violet in the wavelength region between 2900 and 3200 Å comparable with that of the sun.

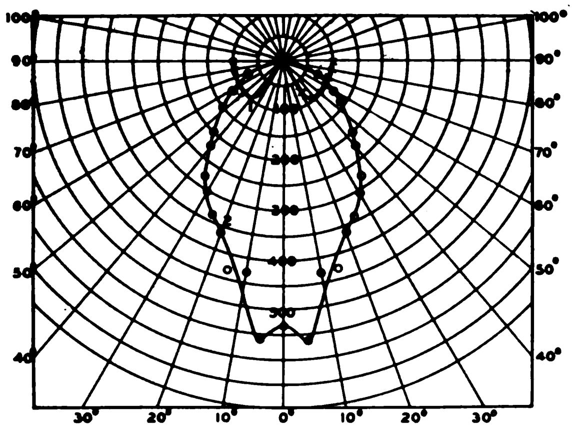

Fig. 14. Ultra-violet Distribution Curve at a Distance of One Meter from the Type S-1 Lamp Alone (Curve *1*), and for the Lamp in a in a Standard Reflector (Curve *2*)

The zero is for the point directly below the lamp. The circles show relative amount of energy for different angles (115 volts applied to the primary of the transformer).

As already pointed out, all the data presented in the article thus far refer to the Type S-1 lamp alone. It was thought that it would be of interest to present some data on the complete unit, *i.e.*, with the lamp in the standard reflector. Since it has been shown that the amount of ultra-violet radiation from the Type S-1 lamp depends on its temperature, it can be seen that if the lamp were mounted in a shade or reflector which would shield it from the air currents so that its operating temperature would rise, its output of radiation would be increased, particularly for the ultra-violet. If this reflector is of some material, such as aluminum, that has a high reflective factor for the ultra-violet radiation, it is possible to get more ultra-violet per square centimeter at a distance of one meter from the lamp in the beam than that from the sun, even when the sun is directly overhead.

In Fig. 14 is shown the ultra-violet radiation below 3200 Å at a distance of one meter from the lamp in a vertical plane perpendicular to the line joining the two electrodes and passing through a point midway between them; for the Type S-1 lamp alone, Curve *1*, and for the Type S-1 lamp in a standard reflector, Curve *2*. The zero for both curves is for the point directly below the lamp with the lamp in a vertical position and the base upward. These data show that directly below the unit at a distance of one meter the amount of ultra-violet radiation below 3200 Å per sq. cm. is about five times as much as the maximum from the bare lamp alone at this same distance. The maximum ultra-violet is radiated in the vertical plane perpendicular to the axis of the arc passing through its central point as shown in Figs. 10 and 11. Curve *2*, Fig. 14, shows that at a distance of one meter from the unit the ultra-violet energy received is practically constant over an area of about 25 cm. in diameter and that it falls off rather rapidly outside of this region. Taking account of the variation of the reflecting factor of the reflector for different wavelengths, these data show that the erythema-producing effect of the unit at this distance and in this direction is equal to about 250 as compared to 100 for June sun and to 50 for the Type S-1 lamp alone as given in Table III.

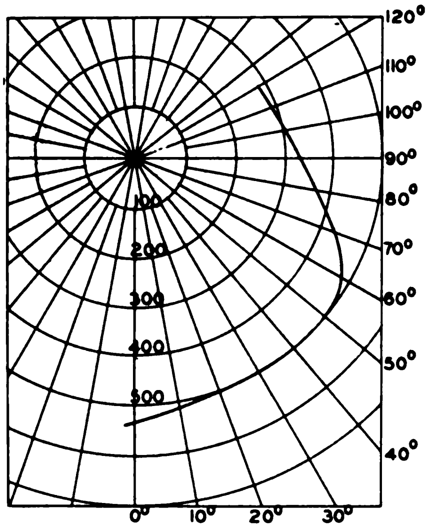

Fig. 15. Polar Coördinate Diagram Showing the Variation of the Ultra-violet Energy Below 3200 Å at a Distance of One Meter Directly in Line with the Axis of the Lamp as the Lamp and the Reflector Are Rotated Around a Horizontal Axis Passing Through the Electrodes (115 volts applied to the primary of the transformer)

The curve in Fig. 15 shows the variation of the ultra-violet energy below 3200 Å at a distance of one meter directly in line with the axis of the lamp (the zero line of Curve *2*, Fig. 14) as the lamp and reflector are rotated about a horizontal axis. This curve shows that the ultra-violet energy does not fall off markedly until the Sunlamp is rotated beyond about 60 deg. from the vertical. This means that it is not necessary to have the lamp pointed directly downward to obtain the full output since there is no marked falling off in the ultra-violet energy below 3200 Å as the Sunlamp is turned around a horizontal axis until it has been turned to more than 60 deg. away from the vertical.

In conclusion the authors wish to express their appreciation of the assistance they have received from a number of their colleagues in this laboratory and also in the Research Laboratory at Schenectady.

IN MEMORIAM

THOMAS ADDISON

The death of Dr. Thomas Addison on April 8 brought to end a life of unusual interest in shaping the growth of the electrical industry in the West.

Dr. Addison was a native of Michigan, attended the University, and graduated from Bellevue Medical College in 1877. Eight years later his activities were directed into channels apart from his original profession; the then-new electrical field became his province. His first connection with it was in the United States Electric Company, of Chicago. In 1888 he became an apparatus salesman for the Thomson-Houston Company; in 1890 he went to San Francisco as local manager of that Company; and two years afterward he was made manager for the Pacific Coast District. Later, largely owing to his skillful efforts, the interests of the western branches of the Thomson-Houston Company and those of the Edison General Electric Company, already merged in the east as the General Electric Company, were harmoniously brought together as a working organization. As Pacific Coast Manager for the General Electric Company, he worked until he retired in 1923.

DR. THOMAS ADDISON

His personal characteristics and temperament are shown in the foresight and wisdom with which he guided the establishment of a great enterprise as well as in the tributes which have been paid to him. Of the former may be noted his recognition of the need of developing adequate means for the utilization of power in a broad economic system—not alone the development of the resource itself. Thus, in the commercial enterprises peculiar to the western states his policies led to the utilization of motors in ever wider and more general applications. In brief, his broad vision and enterprise foresaw and paved the way for the development of industry in the West.

Still, his interests were not confined to industrial activities alone. His duties were shared with scholarly pursuits; and he found time to devote to various public services among which he was Chairman of the Board of Trustees of the State Normal School of San Jose; Vice-President of the Board of Trustees of the Pacific School of Religion, at Berkeley; and a Director in the Berkeley National Bank.

The character and temperament of "the Doctor," who was sometimes also called "The Father of the Industry in the West," are eloquently expressed in the words of a distinguished friend, John Wright Buckham, D.D., of the Pacific School of Religion, whose eulogy at the funeral is printed herewith in full.

The vividness with which a strong personality impresses itself on others after the "grand ordination" of death, as a Scot has called it, is such that words are needless.

The few words which I shall speak of Dr. Addison will be the simple expression by a friend of what is in the minds of us all as we gather here drawn by a common purpose and a common tie.

Whatever is said of Thomas Addison must be in words thoughtful and sincere, for here was a man of great sincerity who chose every word and deed with judgment and care.

He was a man of large capacities and wide interests who kept them in singularly due proportion and harmony. Starting with an active training in the science of medicine, his mind was early attracted to electricity and the extension of its uses and benefits to the everyday needs of human life. Constructively associated with a great business enterprise, he yet maintained an unflagging interest in science, especially astronomy, literature, philosophy, and religion.

He was one of the too few business men who collected and loved a library. His books were his refreshment and joy. Those who have been with him in his library know what his books—and they were the best books, worthy of the high honor of permanence—meant to him.

Yet neither business cares nor scientific and literary tastes made him their victim, nor kept him from giving himself and his abilities to the welfare of the community and the commonwealth in its institutional, civic and social life.

He took part in promoting the good government of his city, was for a considerable period a member of the Board of Trustees of San Jose Normal School, for twenty years was an active member of the Board of Trustees of Pacific School of Religion and for fourteen years Vice-President of the Board. He taught a large Bible class for some time in the First Congregational Church, and was a loyal member for thirty years of the Berkeley Club.

These and other trusts and associations took time and thought and laid added responsibilities on shoulders already, though broad, well laden.

Poignantly acquainted with sorrow and trouble, Dr, Addison met his trials and losses bravely and patiently.

Integer vitae, scelerisque purus—as that fine line of Horace runs—true of life and pure of evil, he kept his integrity and high-mindedness intact, enshrined in a fine dignity and courtesy, and laid his well-chiseled stone firmly and with care into the structure of enduring human values, asking no praise but concerned only to do his duty loyally and well.

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

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Stability of Balanced High-Frequency Amplifiers. J. R. Nelson.
Inst. Radio Engrs. Proc., Jan., 1930; v. 18, pp. 88-94.

Atomic Theory

Some Recent Changes in Our Attitude Towards the Nature of the Physical World. Vladimir Karapetoff.
Franklin Inst. Jour., Mar., 1930; v. 209, pp. 361-372.

Brakes, Dynamic

Recent Developments in Dynamic Braking Lowering. D. C. Wright.
Iron & St. Engr., Feb., 1930; v. 7, pp. 91-94.
(Dynamic braking for hoists.)

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Does the Code Affect Adequate Wiring? A. Penn Denton.
Elec. Wld., Feb., 15, 1930; v. 95, pp. 349-351.

Daylight

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Illum. Engng. Soc. Trans., Mar., 1930; v. 25, pp. 213-261.

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Electric Furnaces With Controllable Atmospheres. C. L. Heisler, Jr.
Ind. Engng., Mar., 1930; v. 88, pp. 136-138.

Electric Lighting—Aviation

Airport and Aircraft Lighting Progress. Edward A. Sipp.
Airway Age, Mar., 1930; v. 11, pp. 377-379.
("The importance of the relation between airport and aircraft lighting.")

Light Beacons for Night Flying. W. M. Hampton.
Aircraft Engng., Mar., 1930; v. 2, pp. 64-65.
("Visibility and fog penetration of various types with a comparison between neon and incandescent lamps.")

Electric Measurements

High-Frequency Resistance Measurement by the Use of a Variable Mutual Inductance. W. Jackson.
I.E.E. Jour., Feb., 1930; v. 68, pp. 296-304.

Measurements of Small D.C. Potentials and Currents in High Resistance Circuits by Using Vacuum Tubes. W. B. Nottingham.
Franklin Inst. Jour., Mar., 1930; v. 209, pp. 287-348.

Electric Transmission

Load Division in Interconnections. Edward C. M. Stahl.
Elec. Wld., Mar. 1, 1930; v. 95, pp. 434-438.

Electric Welding

Electrically Welded Structures Under Dynamic Stress. Morris Stone and J. G. Ritter.
A.I.E.E. Jour., Mar., 1930; v. 49, pp. 202-205.
(The design, strength and testing of welded joints. Abridgment.)

Electrical Machinery

Induced Voltage of Electrical Machines. L. V. Bewley.
A.I.E.E. Jour., Mar., 1930; v. 49, pp. 191-194.
(Describes and discusses a general equation for induced voltages in various classes of a-c. and d-c. machines having parallel coil sides. Abridgment.)

Electrometallurgy

Production of Electric Steel for Castings. George Batty.
Am. Soc. St. Treat. Trans., Mar., 1930; v. 17, pp. 449-470.

Frequency

Frequency Change Problems. Percy Huggins.
Elec. Rev., Feb. 14, 1930; v. 106, pp. 283-285.
("A review of various schemes for arranging changes of induction motors, and a guide to their selection." A situation resulting from the gradual transition from 25 to 50-cycle service in England.)

Generators, Double-Winding

Double Windings for Turbine Alternators. Philip L. Alger and others.
A.I.E.E. Jour., Mar., 1930; v. 49, pp. 225-228.
(Abridgment.)

Hydraulic Transmission

Hydraulics in Design. John P. Ferris.
Mach. Design, Mar., 1930; v. 2, pp. 27-34.
(The first installment of a two-part article on the design of hydraulic power transmissions.)

Insulating Oils

Deterioration and Maintenance of Oil. Colby W. Bryden.
Iron & St. Engr., Feb., 1930; v. 7, pp. 101-104.
("What actually happens to the oil in service." Pertains to both insulating and lubricating oils.)

Oscillators, Vacuum Tube

Four-Electrode Vacuum Tube as Beat-Frequency Oscillators. S. Reid Warren, Jr.
Inst. Radio Engrs. Proc., Mar., 1930; v. 18, pp. 544-547.

Oscillographs

Automatic Oscillograph Used in Connection With Joint Development and Research Work.
N.E.L.A. Bul., Mar., 1930; v. 17, pp. 171-172.
(Describes an instrument which, when continuously connected to a circuit, automatically records transient conditions and the times when they occur.)

Photo-Electricity

Photo-Electric Cells—Competitors of the Human Eye. E. H. Vedder.
Elec. Jour., Mar., 1930; v. 27, pp. 152-158.
(The first article of a series on light-sensitive devices, their applications, and their operating characteristics. Bibliographic lists included.)

Pressure Vessels

Building Vessels for High-Pressure and High-Temperature Service. T. McLean Jasper.
Mech. Engng., Mar., 1930; v. 52, pp. 193-200.
(An account of research work and testing on pressure vessels. Abstract of a paper read before the World Engineering Congress, Tokyo, Japan.)

Radio Communication, Aircraft

Provision of Radio Facilities for Aircraft Communication. E. L. Nelson and F. M. Ryan.
Soc. Auto. Engrs. Jour., Mar., 1930; v. 26, pp. 326-334, 340.

Radio in Air-Transport Operation. Herbert Hoover, Jr.
Soc. Auto. Engrs. Jour., Mar., 1930; v. 26, pp. 321-325, 345.

Radio Receivers

Broadcast Receiver for Use in Automobiles. Paul O. Farnham.
Inst. Radio Engrs. Proc., Feb., 1930; v. 18, pp. 321-326.

Switches and Switchgear

Metal-Clad Switchgear at State Line Station. A. M. Rossman.
A.I.E.E. Jour., Mar., 1930; v. 49, pp. 187-190.
(Describes 22-kv. metal-clad outdoor equipment.)

Transformers, Instrument Type

Method of Testing Current Transformers. W. E. Bruges.
I.E.E. Jour., Feb., 1930; v. 68, pp. 305-307.

NEW BOOKS

(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.)

Balancing of Engines. Ed. 4. W. E. Dalby. 321 pp., 1929, N. Y., Longmans, Green & Co. $8.40.

Electric System Handbook. Clarence H. Sanderson (Editor). 1167 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $5.00.

Electricity Supply Transformer Systems and Their Operation. William T. Taylor. 243 pp., 1929, Lond., Charles Griffin & Co. 20 s.

Elements of Engineering Thermodynamics. Ed. 4. James A. Moyer and others. 195 pp., 1929, N. Y., John Wiley & Sons. $2.50.

Gaseous Combustion at High Pressures. William A. Bone and others. 396 pp., 1929, N. Y., Longmans, Green & Co. $15.00.

Heat Loss Analysis. E. A. Uehling. 241 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $2.50.

High Voltage Cables; Theory and Practice of Their Design and Operation. P. Dunsheath. 161 pp., 1929, N. Y., Isaac Pitman & Sons. $3.00.

(Based on a course of lectures delivered by the author at University College, London, in 1928, the object of which was "to summarize the accumulated mass of information and make it conveniently available for the many engineers and students who cannot hope to see all the original published literature." The book is offered "as a general statement of the position today, with the finger pointed in the direction of future development in those cases where the probability is already evident." The initial pages are devoted to a consideration of the growth and economic features of high-voltage underground transmission. Then follows a discussion of the properties of dielectrics, dielectric loss, and power-factor. Stress and breakdown, and the related topic of time-voltage relation, are next given a chapter. The physical properties of impregnated paper cables; belted, screened, and "S. L." cables; single-core cables; and current rating and stability are each given attention. The two concluding chapters treat of joints and terminals and of a few special cables and systems, including oil-filled cables. Lists of the more important published papers on the various topics are appended to the chapters.)

Photoelectric Cells; Their Properties, Use, and Applications. Norman R. Campbell and Dorothy Ritchie. 209 pp., 1929, N. Y., Isaac Pitman & Sons. $4.50.

(The authors have chosen to regard the photoelectric cell "not as an illustration of important laws and theories, but as a laboratory or workshop tool." To this end they "consider principles and theories only in so far as they bear upon practice." They have thought it wise to devote more space to problems and methods which they themselves have studied and used than to those they have not, hoping thereby that what their treatment "loses in width it will gain in depth." On the other hand, they have attempted at least to mention, in addition, all the larger problems and all the sound methods revealed by the investigations of others.)

Principles of Radio. Keith Henney. 477 pp., 1929, N. Y., John Wiley & Sons, Inc. $3.50.

("Written for the man who must study without a teacher as well as for those who attend schools where courses in radio are given . . . . It starts at the very beginning, with the fundamental principles of electricity, and develops the subject of radio practice in a clear, logical and simple manner. Scarcely any mathematics beyond arithmetic and elementary algebra is needed to work out the problems and examples illustrating the text." In his eighteen chapters the author considers, in addition to the elementary principles of electricity, such topics as inductance and capacity, coils and condensers, alternating-current circuit phenomena, resonance, vacuum tubes and their applications, amplifiers in their various types, detection, receivers, rectifiers and power supply apparatus, oscillators and transmitters, and antennas and transmission. In his treatment he has so combined the theoretical with the practical that the text is one well fitted for the beginning student of radio.)

Standard Wiring for Electric Light and Power. Ed. 36. H. C. Cushing, Jr. 512 pp., 1930, N. Y., H. C. Cushing, Jr. $3.00.

(The thirty-sixth annual edition of this well-known handbook presents "the essential requirements for safe and efficient wiring and construction for electric light, heat and power in accordance with the National Electrical Code, and the latest engineering practice, together with explanatory and helpful notes, illustrations, definitions and tables for the guidance of the man who does the work." This most recent edition includes new sections on the "Red Seal Plan" for house wiring; the "Franklin Specification" for industrial, commercial and public buildings; residence lighting; theater and motion picture house wiring; radio wiring; etc.)

Steel Treating Practice. Ralph H. Sherry. 399 pp., 1929, McGraw-Hill Book Co., Inc. $4.00.

The Electro Magnet. Ed. 3. Richard Varley and Thomas W. Varley. 175 pp., 1930, Englewood, N. J., Richard Varley.

(A useful little volume on the history, fundamental principles, and design of direct-current electromagnets. Many full-size illustrations of electromagnets, together with specifications, performance curves, weights, ratings, and data on windings and tractive efforts, are included. The first chapter is devoted to historical matter, with special attention to the contributions of Joseph Henry. The second chapter, by Edward Heitman, studies the general properties and theory of the electromagnet. The third chapter, by Dr. A. E Kennelly, is "On the Relative Values of the Windings of Electromagnetic Coils." Chapter four considers the two-spool magnet, and chapter five the iron-clad plunger magnet. Chapter six is devoted to winding formulas, with examples; and the final chapter presents wire and winding tables and a few useful mathematical tables.)

Wave Mechanics; Being One Aspect of the New Quantum Theory. H. T. Flint. 117 pp., 1928, N. Y., E. P. Dutton & Co. $1.25.

("This little book is written in the hope that it will be of assistance to those who are interested in the most recent development of physics; the new method of approach to atomic problems. The aim has been to present to the reader in a reasonably simple manner an account of the theory, with its relation to existing physical theory, as developed by de Broglie and Schroedinger. This theory is properly called Wave Mechanics, and it is based on conceptions of continuity." The author divides his work into five short chapters as follows: "The Variation Principles of Dynamics and Optics," "Mechanical Waves," "The Nature of the Problem and its Solution," "Evidence for the Existence of Mechanical Waves," and "The Physical Significance of the Wave Equation and the Wave Function.")

X-Ray Technology; the Production, Measurement and Applications of X-Rays. H. M. Terrill and C. T. Ulrey. 256 pp., 1930, N. Y., D. Van Nostrand Co.

(In their preface the authors say: "It has been the purpose in preparing this book to present the practical rather than the theoretical aspects of x-ray measurements as they are inevitably encountered by all who choose to work in the x-ray laboratory. Much of the contents is devoted to problems which are common to all x-ray laboratories but particular attention has been given to the quantitative measurements involved in x-ray therapy and in industrial applications. A considerable portion of the contents may be properly classified as x-ray engineering. Much space has been given to the description of instruments and apparatus and methods of using them, since it is recognized that in the x-ray laboratory it is often necessary to make use of special equipment which cannot be obtained except by constructing it in the laboratory workshop." The topics considered in the eleven chapters are: properties of moving electrons; x-ray tubes and their operation; high voltage generators; measurements of voltage and current, of ionization, of total energy, of wave-length, and of biological phenomena; radiography; and x-ray analysis.)

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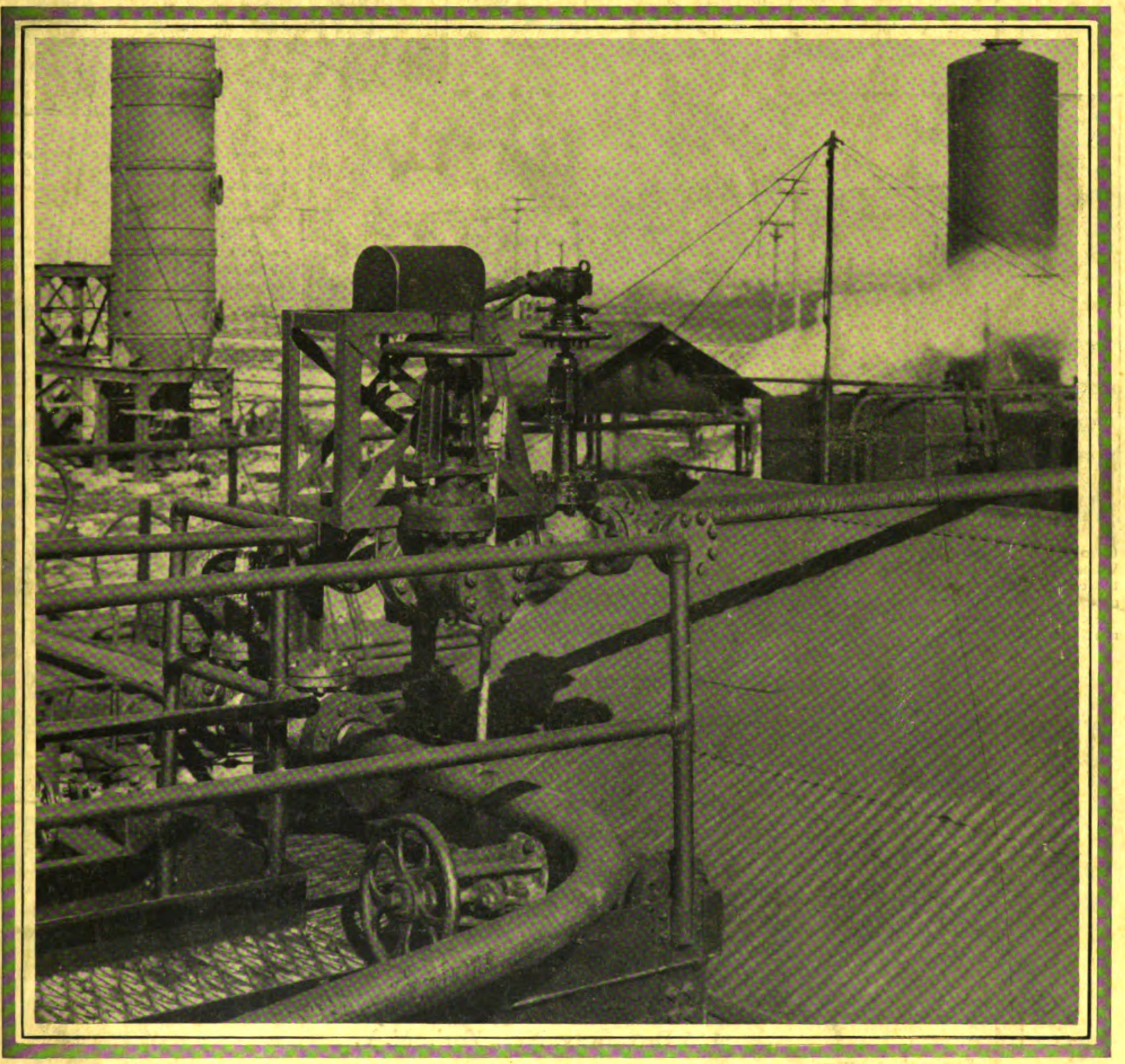


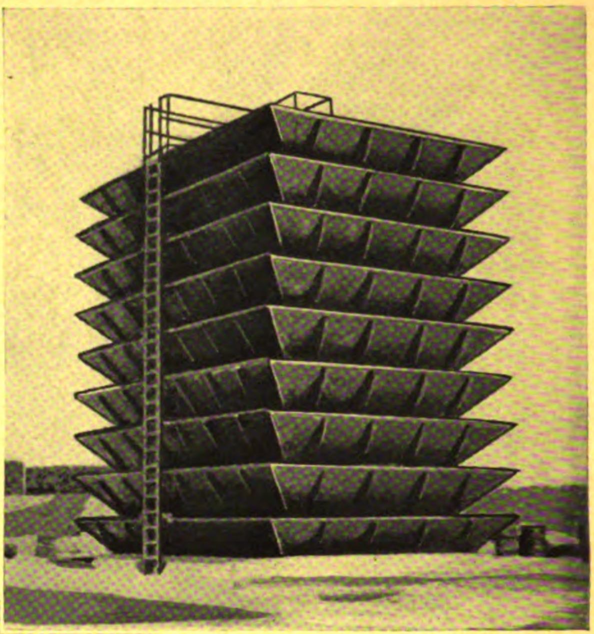
A VALVE UNDER CENTRALIZED CONTROL

This is an application of a Selsyn motor to the release pressure valve on the condenser of an oil-cracking unit. For remote valve operation, pump control, and kindred operations in the oil refining industry, and in a broad field of usefulness in industry at large, this form of control is well adapted. *(See p. 378)*

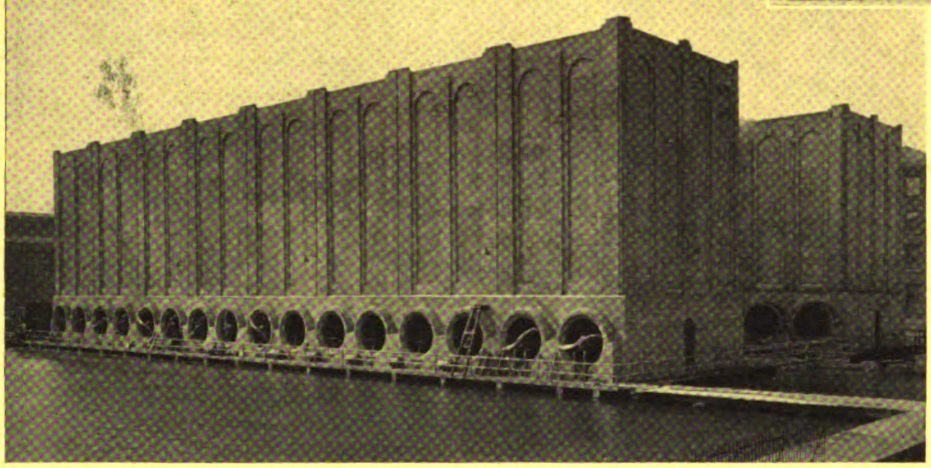
In This Issue:

- *Joints in Heavy Electrical Conductors*
- *Politics and Economics*
- *Modern Physics*
- *Selsyn Control Equipment*
- *High-voltage Insulators*
- *Force Between Reactance Coils*
- *Crystal Orientation*
- *Transformers for Arc Furnaces*

Cooling Towers for All Purposes



(Above) Foster Wheeler atmospheric type cooling tower. Towers of this type are especially adaptable for cooling circulating water of electrical transformers. They are constructed of a special grade of California redwood and produce a structure remarkably free from defects in materials or workmanship.



(Above) Two batteries of Foster Wheeler forced draft cooling towers. Eight-foot diameter aeroplane type fans furnish the draft for these towers which are 50 ft. high.

Cooling towers are furnished by Foster Wheeler in sizes and designs to meet any requirement. The small atmospheric type tower as shown in the upper right photograph is especially adaptable for cooling the circulating water of electrical transformers, internal combustion engines and refrigeration systems.

Contrasted to the small atmospheric tower, is the large forced draft cooling tower—using aeroplane type fans—shown at the left. This cooling tower installation will cool 87 million gallons of water per day. Between these two extremes are Foster Wheeler cooling towers of varying capacities and styles.

The choice of a cooling tower depends largely upon local conditions and specific requirements. Without obligation, a careful study will be made of your problems and recommendations made for the most suitable tower.

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monthly by *INDUSTRIAL ARTS INDEX*, and weekly and annually by *ENGINEERING INDEX*; and abstracted monthly by *SCIENCE ABSTRACTS*

OWEN D. YOUNG

GENERAL ELECTRIC
REVIEW

Vol. 33 July, 1930 No. 7

POLITICS AND ECONOMICS

We publish in this issue the masterly address delivered by Mr. Young on the occasion of the Sixty-second Anniversary of the University of California. We are apologetic for our tardiness, as Mr. Young's great pronouncement was made as long ago as March 24th. We feel, however, that this powerful address must be published in our columns as we are so proud of the fact that the author is both Chairman of that great International Committee which bears his name, and Chairman of the Board of Directors of the General Electric Company.

While we feel any editorial comment on Mr. Young's remarks may be mistaken for an attempt to paint the lily, we also feel that a word of appreciation is in place.

His fearless utterances on the most controversial subject of his time show statesmanship in every line. Who can but welcome the idealistic note that runs through the whole? He flatly refuses to acknowledge Politics and Economics as the Masters of Mankind, he would make them both our servants; and further than this, he recognizes no political boundaries to our individual and collective efforts to alleviate economic wrongs. He gives our future plans for human well-being a paramount position and would make them as world-embracing as the great field for radio communication. Indeed he puts the broadest possible interpretation on a grand old law of culture—"Let each become all that he was created capable of being"—and he would apply this great precept to nations as well as to individuals.

"All the world's a stage and all the men and women merely players." So Mr. Young marshals Politics and Economics before his audience dressed in the garments they wore for the last curtain call in the world's greatest tragedy. Both were then suffering from shell shock.

Mr. Young with his unique experiences and world-wide contacts is the greatest authority on the subject with which he deals. He alone has the skill and artistry to personify and portray Politics and Economics as he does throughout this remarkable address. His subject may be a closed book to many, but in reality is of fundamental importance to all, and should be given more thought in normal times.

Mr. Young points out in the most simple language that if we are to let some, under the handicap of a great burden, outstrip us in harvesting that which Science and Research alone can produce, we shall be the weaker rather than the stronger in the end. Our world problem is the more equitable distribution of the golden grain that Science and Economics produce.

We must think internationally; and Politics must break down some of her artificial barriers. Statesmen must heed the voices of Science and Economics. There is no permanent blessing in being too rich to be loved—there is no security in being over-much envied.

National selfishness in the long run may spell suicide. History teaches us that political boundaries are insecure and transitory. Unjust burdens on others can, and most likely will, react as curses on ourselves.

We salute Mr. Young for the great good he has done in making these courageous utterances and we feel that he is one who is capable of leading Science, Economics, and Politics into the broader paths of International Statesmanship. J. R. H.

Politics and Economics in World Affairs

By OWEN D. YOUNG

Chairman of the Board of Directors, General Electric Company

(Address by Mr. Young at the celebration of the Sixty-second Anniversary of the University of California.)

IF one were to speak on international affairs, it would be fitting to do so at one or the other of those great ports which are our most sensitive contacts with the outside world. Through New York and San Francisco, inward and outward, flow in substantial part the great movement of men and things which constitute international transportation; of voices and records which make up international communication; of finance, that essential mechanism through which all these interchanges are made possible.

It is true that Washington, as the political focus of the nation, makes our political contacts abroad, but they are relatively superficial and inconsequential compared with these sensitive forces of quick and constant action which represent our participation in the economic activities of the world. So, after the completion of the Dawes plan, I spoke of my experiences abroad first in New York. Now, after the completion of the new plan, I consider it a privilege to say my first word at the great port of entry of the West. It is perhaps not inappropriate that it be said as a part of the celebration of this significant anniversary in the life of the University of California.

On the 11th day of November, 1918, the military forces engaged in the great war suspended operations. For more than four years they had been our masters. They commanded our thoughts and our ambitions; they held as hostages our property and our lives; politics had retired to second place; economics had temporarily been forgotten.

Politics Comes to the Fore

After the military had suspended its act in the tragic drama, Politics and Economics again came on the stage. Politics, as she advanced to the footlights, had never seemed so charming. She received the applause of all the world. How delightful it was to get rid of that old witch of war who destroyed our wealth and our peace of mind, who murdered our sons and who disarranged all the notions of our daughters! Is it any wonder that Politics commanded our admiration?

What high hopes we had of her! True, there was on the stage also a very modest being, ragged in clothing, bewildered in her senses, known as Economics. No one paid much attention to her in comparison with their lovely idol. Truly, Politics was mistress of the world. And with that setting, the play went on.

Politics, conscious of her power and with impatient hand, wrote a treaty while all the world was lost in admiration of her daring. In those days a part of her charm lay in her many moods. One day she spoke through Woodrow Wilson, and the audience sat breathless, moved by the high idealism of a great man and the rich expression of a master. Another day, by contrast, she was hard and cynical, and what the world calls practical, as she spoke through Clemenceau. And still another time she had the delightful abandon and irresponsibility of a mischievous mistress as she was impersonated by Lloyd George. And she had courage, too, because she swept away age-old boundaries and made new ones.

True, occasionally was heard the weak voice of Economics modestly protesting here and there, occasionally even offering advice, only to be silenced by the imperious gesture of the leading lady. And one day she decided that Germany was to pay by way of reparations the sum of 132,000,000,000 marks, or one-quarter as many dollars. Then it was indeed time for Economics to speak, and she did, in protest. But she was quickly silenced by the great party in the Palace of Versailles, the scene of so many grand affairs. Had not Politics always been mistress of Versailles? Had not Economics always been a scullery maid? Why break the precedent now? Why listen to her in these great councils—and they didn't. And then "The tumult and the shouting dies. The captains and the kings depart."

Takes Economics on Tour

Permit me to carry the figure one step further. Politics now goes on tour, always taking her bedraggled associate with her, because even Politics knows that Economics must do the work. Politics in France says, and properly and sympathetically so:

"Your houses and lands have been destroyed, rebuild them, and do it handsomely—others will pay the costs." That was the program which Politics could start but which Politics could not stop. So the building went extravagantly on, and a few years later, when Germany failed to pay the cost and consequently there overhung France this addition to her vast interior debt, Politics said:

"We will make Germany pay. We will move our armies into the Ruhr and compel by force the production of coal and manufactured goods for reparation account."

But it turned out that the sword was a poor instrument with which to get economic results. Politics could put a French army in the Ruhr, but Politics could not take it out.

Politics in England said: "If there be people out of work, or even people who do not want to work, give them a dole from the public treasury."

How generous she was! But there was a program which Politics could start but which Politics could not stop.

Politics in Germany said to Economics: "You seem depressed this morning with the great work you have to do. Let me give you a cocktail. I do not intend to get you intoxicated. Take a little stimulant, and after you are started, we will cut it out."

So Politics gave to Economics inflation. That was something which Politics could start, but which Politics could not stop. As a result, the currency of Germany was destroyed and her people were plunged into the depths of want and despair. Yes, it is easy for Politics, with her appeal to the emotions and her ingratiating manner, to start things in the field of Economics which she cannot stop.

Economics Gets a Hearing

And so it happened in the autumn of 1923. Then, for the first time, Economics got a hearing. The world began to doubt whether Politics, with all her charm, was safe and sound. Losing the applause of her audience, and with that something of her confidence, wringing her hands in despair, Politics finally called to Economics and said: "If I give you the opportunity will you try to save the show?"

The Dawes committee convened in Paris on the 14th day of January, 1924. Its task was to provide a plan for the balancing of the German budget and for the stabilization of the German currency. It was not permitted to revise the amount of 132,000,000,000 marks which Politics had fixed for Germany to pay. So the Dawes committee did the very simple thing of fixing the annual installments which Germany should pay on account of reparations. These being fixed, the budget could be balanced and the currency stabilized. The Dawes committee did not specify the number of years which the installments were to run. No one ever computed the years, because it was apparent to the world from the size of the installments that the earlier reparation figures had been in fact, if not in law, abandoned.

The Dawes committee brought out its plan on the ninth day of April, 1924. It was made effective on Aug. 16, 1924, at the conference of London by a treaty signed by the nations which were the beneficiaries of German reparations. By it a new central bank was established for Germany and a new currency was created with an adequate gold supply.

And to give you an idea of the results of the inflationary intoxication, let me say that one mark of the new currency was exchangeable for one billion marks of the old currency, and I mean the Continental billion not ours; that is to say, a million million old marks for one new mark.

World Learns First Big Lesson

And so Economics took the stage in Germany on the first day of September, 1924. A few days later the French armies began to move out of the Ruhr back home. The Germans began to work their mines and factories. The world learned its first great lesson—that economics does not function under political threats or military coercion. It performs obligations which are reasonably fair. It recognizes in the long run only self-interest and honor.

In a word, the world learned that coal and steel for reparations would come at the point of a pen on a checkbook, and would not come at the point of the bayonet in the hands of the soldier. Certainly it was demonstrated that in this field the pen is mightier than the sword.

You all know the story of Germany's economic recovery under the Dawes plan. She paid to her creditors during those five years the full amount set out in the plan, namely, 7,600,000,000 marks which is the equivalent of $1,917,000,000. Nevertheless, the Dawes plan was a receivership plan for Germany. It was not a plan of permanent reorganization. Under it S. Parker Gilbert, a brilliant young American, was the receiver, and let me take this opportunity of saying that the success of the Dawes plan was largely made possible by his wise and efficient administration of the receivership. May I step aside long enough to call the attention of the students of California to the fact that Parker Gilbert was made Agent General for Reparations Payments at the age of 32? He was graduated from Rutgers College in the class of 1912, and from the Harvard Law School in the class of 1915. I speak of it here only because I want you to know that great opportunities and responsibilities lie before you, not somewhere in the distant future, but almost here and now.

As I have said, the Dawes plan was an interval receivership plan—it did not even fix the total amount of the debt, although all the world knew that the original sum fixed by politics was quite impossible. Then, too, one could not expect a great nation of 60,000,000 people to function permanently in the hands of a receiver, and so at Geneva on October 20, 1928, Economics was again called by Politics, in the form of an experts committee, to make proposals for a complete and final settlement of the reparation problem. That committee met on Feb. 11, 1929, in Paris, and on June 7 signed and transmitted its report of final settlement. That report is popularly known as the Young plan.

Spirit in which Plan Was Made

May I say in passing that this habit of adopting the name of the chairman as the name of the committee began when the first experts committee was christened the Dawes committee. General Dawes was not keen about that change of name, but he said, you will remember, that somebody had to take the garbage and the garlands. It was in that same spirit that the Young committee and the Young plan were so named—and you may be sure that the chairman will receive more than his fair share of social prestige at the front door and a proportionate amount from the can at the back door, depending wholly on whether the affair is an afternoon tea or the "morning after" clean-up.

By the Young plan, the annual installment of the Dawes plan of 2,500,000,000 reichsmarks, plus a variable resulting from an index of prosperity, was reduced to an average for the first thirty-seven years of 2,050,600,000 gold marks, that is to say a reduction of 20 per cent or more. The annuities begin at 1,707,900,000 marks and advance slowly toward a maximum of 2,428,800,000 marks. After the first thirty-seven years, the German installments gradually diminish from approximately 1,600,000,000 gold marks in 1966 to 897,800,000 in 1988.

Under the plan, the receivership of Germany is withdrawn. The mortgage of $2,500,000,000 on the German railway system created by the Dawes plan, is discharged. The general mortgage on German industry of over $1,000,000,000 is also lifted. Germany is given a specific task to perform. Foreign armies provided by the political treaty are withdrawn. The Reparation Commission is wound up.

German Honor Alone at Stake

Care was taken in the plan to avoid the term reparations. And so at last, ten years after the armistice under the new plan as drawn in Paris, Germany is free. She has a debt to pay, but that is all. Her honor, not her freedom, is at stake.

May I say a word about the problems and difficulties in Paris? I have told you that the Dawes payments were reduced something like 20 per cent and the total number of years which Germany should pay was also fixed. These installments, computed at their present value, represented a charge on Germany of something like $9,000,000,000, or 36,000,000,000 marks. Politics, you will remember, fixed Germany's obligations at 132,000,000,000 marks, or $33,000,000,000. In a word, our kitchenmaid, Economics, was compelled to cut the menu of her leading lady by more than 70 per cent to make it fit the prospects of the larder.

Politics Reappears at Hague

At The Hague, Politics again appeared, and while protesting that she did not wish to put larger burdens on Germany, did increase somewhat—sufficiently for political purposes, I dare say—the burdens of the Paris plan; and most of those burdens do, in fact, ultimately fall on Germany. Then, too, at the second Hague conference, Politics again made an effort to substitute military sanctions for Germany's nonperformance, and in a most attenuated form such sanctions were provided.

Economics does not like military sanctions. Dr. Schacht protested, and has recently resigned the presidency of the Reichsbank because he was unwilling to assume responsibility for the execution of a plan which carried burdens additional to those imposed at Paris, and which had any color of military sanctions. Dr. Schacht has been accused in taking this action of having domestic political ambitions. It is fair to him to say that his protest arose, not because there was politics in Dr. Schacht, but because politics had again crept into the plan.

However, I have no fear of the slight political tinge which the plan took on at The Hague. Certainly this settlement was better than none. It would have been a great catastrophe for Germany and all the world had the plan agreed upon at Paris by the representatives of all the countries, including Germany, failed in the hands of Politics at The Hague. We are all to be congratulated that it did not do so, and perhaps most of all the government of the United States.

America to Get More Than 60 Per Cent

I speak of my own country, because more than 60 per cent of the total sum to be paid by Germany must find its way to the United States in payment to us of the so-called international debts. You see that was one of our serious problems at Paris. Roughly, one-half of the Dawes payments were needed by the creditors of Germany to pay their debts to the United States. That obligation was fixed. So the entire reduction by the creditor countries in the Dawes payments, so far as their respective budgets were concerned, had to be made out of one-half of the payments; that is, every 5 per cent reduction to Germany in the Dawes plan payments meant a 10 per cent reduction in the net budget benefits of the creditor countries.

Now a 20 per cent reduction in the Dawes plan payments looked small to Germany, but a resulting 40 per cent reduction in net budget benefits to the creditor countries looked very large to them. That was one serious problem at Paris.

Another was that the Dawes plan payments were distributed under what was known as the Spa percentages. Now, as the reduction in the German payments took place, some of the countries, notably Italy, under those percentages, would not have received enough to pay their indebtedness to the United States, while others would have a considerable surplus. Therefore, in order to secure a settlement at all, it was necessary at Paris to remake these percentages.

We not only had to set the total amount which Germany should pay, but we had to redistribute that diminished amount among the creditor countries so that all would be satisfied. The problem of fixing Germany's total amount was not as difficult as the redistribution among the creditors. The German problem was largely an economic one. The redistribution problem was largely a political one.

So, unfortunately, from my point of view, the Young committee in Paris had to deal with these combined problems of economics and politics. If I show some dislike for Politics today, it results largely from my experience with her in Paris. Charming as she may be at times on the stage, she is often petulant and petty, and always selfish, in the dressing rooms, and, habitually, she puts a low estimate on the intelligence of her audience.

Best That Could be Done

However, as I say, a settlement was made in Paris. It was the best settlement that could be made. Strictly speaking, it was neither an economic settlement nor a political one. It was a compromise between the two.

The compromise was difficult. Both politics and economics in all countries had been waiting for this day of final settlement to even up some of their old scores. Things which had been said and actions which had been taken, things which had been left unsaid and actions which had been withheld, were now to be brought on the stage for the last time.

So, in a sense, our committee at Paris was compelled to review and reargue, and so far as possible adjust, all of the conflicts involving reparations and their redistribution, and everything collateral thereto which had arisen during the preceding ten-year period. Questions of parity and ratios which are so important to guns and ships, were not by any means absent in dealing with a limitation program expressed in currency.

Perhaps you will pardon me if I stop here long enough to pay a slight tribute to my associates in Paris. They were men of competence and independence in thought and action. Economic theorists could not dominate them. They had the highest regard for the specialized expert, but they also had experience in making practical application of expert theories. Financial or business interests could not coerce them. They had the greatest respect for men of business, but they were not blind to the large social and political factors also involved. Politics could not control them because they held no public offices and were not responsible to political constituencies.

Friendship a Factor of Success

From such a group only could a settlement come. That does not mean that it could come from these individuals only, but it does mean that individuals, to be successful, must have the qualifications which I have indicated. Then, too, the members of this committee had the good fortune of intimate personal acquaintance. Most of them had been friends for many years. This was a contributing factor to success.

I wish I might take the time to speak of each member of the committee individually and give you some idea of the value of his contribution, particularly as to my American associates. It must suffice here for me to say that no man ever had more competent and loyal associates than I had in J. P. Morgan, Thomas W. Lamont and Thomas Nelson Perkins. The respect in which they held each other and in which they were held by their European associates had a very great influence on our work.

Whether the burden placed on Germany is too great, only time will tell. It is true that the countries participating in the Paris plan have added all of their indebtedness to the United States together, and added approximately 50 per cent to it, in fixing the sum which Germany is to pay. Each of those countries, you will remember, had protested against the burden of their indebtedness to the United States, even under the favorable debt settlements made.

Yet they have paid Germany the compliment of assuming that she can bear the burden of them all, together with a substantial premium.

But I have great confidence in Germany's capacity to pay. True, she has not a large supply of what the world calls basic raw material. She has, in large measure, however, a supply of that kind of raw material too little taken into account in the world's affairs, namely, a capacity for scientific research, and the ability to apply it and organize it in production. It is not unlikely that in the years to come this particular kind of raw material with which Germany is well endowed may be the reservoir out of which these vast sums will be produced and paid.

If Germany does make the payments out of such a reservoir, the rest of the world must be careful to avoid the enervating effects resulting from the receipt of such payments. We should all remember that the discipline of hard work and of heavy responsibility is likely to do much for a people as well as for an individual. Let no man be sure, let no nation be sure, merely because he is a creditor of some one else's labor, that therefore he is strong and will always remain so.

The International Bank

The most striking feature of the new plan is the Bank for International Settlements. That institution is unlike anything which has existed in the world before. It was not created merely for the sport of inflaming the imagination of men, or even for the laudable purpose of providing a new subject for the debaters of the world. Like all inventions and new creations, it arose out of the mind of man to meet a new need.

Obligations, as I have said, are to be delivered by Germany of approximately $9,000,000,000, payable over a period of nearly sixty years, in fixed annual installments. As these obligations mature, vast sums must be paid over frontiers and translated into the currencies of other countries. Who should hold these obligations and control these transfers?

Should they be put in the hands of political treasuries of more than a dozen nations, where, in case of slight difficulties, they might become the football of domestic or international politics? Even more dangerous would it be to have them become the trading medium in all kinds of international negotiations.

Should they be left where Germany, if she chose, might default in the payments to one power and continue those to another?

Should they be left where these transfers in political hands might become a menace to the normal economic exchanges of the world?

No, it was quite apparent, in the interest of all,. creditor and debtor alike, that these obligations of Germany should be held and the payments managed by a single organization for the account and benefit of all. Any default by Germany must be a common default for all creditors. Any moratorium must be a common moratorium. Therefore, it seemed to our committee necessary to mobilize the German obligations in single hands.

Status of the Institution

For that purpose the Bank of International Settlements must be between Germany and the bank. The bank should be, as far as possible, insulated from politics, both domestic and international, and be free from government domination and control. To accomplish this, the charter and by-laws of the bank were established by international treaty and evidenced by a protocol signed at The Hague, on Jan. 20 of this year. Corporate entity is to come into existence by an act of the Legislature of Switzerland, where the bank is to be located, Switzerland being a party to the treaty.

The capital of the bank is to be $100,000,000, and its stock is to be sold to private persons in the principal countries of the world. Its directorate is to consist principally of the governors of the central banks of Europe, or their nominees, America having declined to participate.

The earning power of the bank is to come from small commissions on reparation payments, and certain deposits from governmental treasuries provided in the plan. The bank has power to accept deposits from or to make deposits in central banks of countries on a gold exchange basis. Thus the endeavor has been made, in the interest of the world, to eliminate politics from the control of reparation payments, and from the machinery which will handle them. The bank is to be truly the insulator between the political treasuries of the creditor powers and their debtor, Germany.

Things the Bank Cannot Do

The bank is in no sense a super-bank. It cannot operate in any country in which the central bank of that country objects. It cannot issue demand notes in any form, and therefore there is no danger of an international currency.

It may be used as a clearing house by central banks to the extent which they may elect to do so. This lies in the future. But there is no question in my mind that some such development will come about if the diminishing supply of gold in the world threatens a general deflation in the price level. The proper handling of price stability is one of the most important matters facing the capitalistic system today. In it will be found the roots of these maladjustments which result in the unequal and unfair distribution of wealth, in unemployment and other serious problems.

The international bank may turn out to be an essential and useful piece of machinery for an economic world which of necessity is becoming more and more closely integrated. Politics becomes dangerous on a stage so small unless economics functions well. Fortunately the bank has the power of growth, but it will grow only as our needs compel it. It will grow only as the central banks of the world wish to use it. In a word it is the servant of all and the master of none.

Will Stay Independent of League

The question has been raised whether the League of Nations and the Bank for International Settlements might not unite their forces. The League represents international political coöperation, and the bank international financial coöperation. Well, if that means that the bank will come under the domination of the League, and so there will be added to the political forces of the League the financial resources of the bank, I think we may dismiss once and for all our fears if we are opposed to the League, or our hopes if we are its proponents.

Nothing is clearer, from the experience of the last ten years, than the necessity of keeping our economic machinery, and especially our finance, free from the domination and control of politics. That seems to me one great lesson which we have learned. I do not mean that the struggle of politics to control economics is ended. It is going on in every country, and will continue to do so.

But what about the relationship of economics to politics in international coöperation? Well, my answer is this: Economic integration of the world is a necessary prerequisite to effective political coöperation in the world. America, as the greatest creditor nation, is more interested than any other in economic integration. It is inevitable that from an economic point of view she take an interest in and be concerned in the material problems and affairs of every country on the globe.

Our Isolation Seen as Impossible

Isolation to America, either economic or political, is impossible. The material development of countries will necessarily be to us a matter of great concern, both from an idealistic and practical point of view. If all peoples everywhere could be lifted in productive capacity and consuming power to a point equal to our own, envy and hatred would be alleviated; capital would be better employed; markets would be enlarged; unemployment would diminish, and a much more peaceful world would be insured.

Let no man think that the living standards of America can be permanently maintained at a measurably higher level than those of the other civilized countries. Either we shall lift theirs to ours or they will drag ours down to theirs. Tariffs and other petty political barriers, temporarily justifiable, will, in the long run, only accentuate the trouble.

Our experience at home during the last generation should teach us that segregation into different groups for the selfish purpose of benefiting one at the expense of the other is a failure. It was not so many years ago that our industrial leaders in the United States thought that a low wage scale was necessary to enable capital to earn a profit. Now we have learned that a high wage scale may be consistent not only with low production costs but also with the greatest security to and return on capital investment.

In a word, we are learning in America that the highest welfare of all rather than of any class is a wise objective even for the group previously privileged. How long will it take us to learn that fact in a world so small that Commander Byrd talks from New Zealand on Wednesday at noon, in the fall of the year, with Adolph S. Ochs in Schenectady, on Tuesday, at 7:30 a. m., in the spring of the year—and that conversation can be heard by practically everybody in the world at varying times and seasons?

Must Pass Political Frontiers

It is too late, in our own interest, to think in terms of selfish isolation. To secure the advantages of economic equilibrium we must go beyond political frontiers. We may sign great declarations of peace, but we shall concurrently find, if we follow a narrow economic policy, an increasing resistance in countries less well off than ourselves to that disarmament which is the insurance of the peace we seek. Politics in America may start a program which politics cannot stop.

After all, we must remember that politics and economics are not the masters of men—they are their servants. The managers of both too often think and sometimes act as if human beings were merely the fodder of political and economic mills. Merely because I have spoken of economics and politics I would not wish you to think that I consider them in any sense ends in themselves. Back of them stand myriads of human faces, some young, some old, some prosperous, some needy, some charitable, some selfish, some generous, some envious, but all vitally affected not only in their material but in their cultural and spiritual development by these organizations, political and economic, which they have imposed upon themselves.

So long as such organizations render an uplifting service just so long can we go forward in reaping the advantages which civilization has brought. But those faces in these days of a closely compact world can no longer be segregated into compartments, one of which shall be prosperous and the others not; one of which shall go forward and the others back. Those faces must all move together for good or ill. So politics and economics, their servants, must move together too, not in one country alone, but everywhere. That way only can the benefits of civilization be enlarged—that way only can peace come.

And one word more. America is too rich to be loved. She is well enough off to be envied. The attitude of the world toward her will be largely influenced by her spirit.

If it be one of selfishness in isolation, she will have failed in her great responsibilities. If it be one of boastfulness in her success, she will have misused the things which God has given her.

I pray for sober and sensible responsibility, a spirit of gratitude for the things we have, a spirit of friendliness and helpfulness and coöperation for all, a spirit of restraint in the use of any power which has been entrusted to us, and most of all, restraint in speech.

"If drunk with sight of power we loose
Wild tongues that have not Thee in awe,
* * * * * *
For frantic boast and foolish word
Thy mercy on Thy people, Lord."

Applications of Selsyn Remote Control in the Oil Refining Industry

General Requirements of Process Control—Applicability of Selsyn Equipment—Use of Selsyn Control in Valve Setting—Description of Mechanisms—Applications to Cracking Units, Fractionating Towers, and Pump Control

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PROGRESS in oil refinery design over the past few years has been made possible in a large measure by the ever-increasing facilities for the control of the various operations of refining. Instruments of all kinds have been developed to permit greater knowledge of operating conditions and in many cases to maintain automatically the relationship of flow and temperature which are essential to economical and efficient operation. Continuous processing, which has superseded batch operation almost entirely, has created the necessity for closer control and a careful matching of rates of feed to produce desired results. The satisfactory operation of either distillation units, cracking units, or treating plants now more than ever is dependent upon the centralization of the control of processing to one mind, thus reducing errors due to the division of responsibility.

The design of almost all refinery equipment involves a system of piping, and indications of the conditions throughout the system are registered or indicated by pressure gauges, pyrometers, and various recording instruments. This part of the equipment has been developed fairly rapidly and the practice of installing the various instruments required for a process at a central point has now become standardized. These instruments furnish the knowledge of what is happening in the system but as yet comparatively little has been done to translate their readings into control. The control of a refining unit is effected by variation of valve settings which in turn operate either directly on the flow of oil, fuel, or in the change of motive power of pumps or other similar equipment. It is generally necessary for the operators to note the conditions being maintained in the system and, when necessary, to issue orders to have them changed. The changing of any individual control requires not only the necessity of making the correction, but a careful judgment as to its magnitude. In the complex systems developed to handle oil in large quantities, almost all the controls affect each other to some extent and the problem of operating a unit becomes one of balancing rates of flow in all parts of the system. Especially to those who have studied the operation of refinery apparatus, it will be evident that the man whose duty is to observe the changes which take place in the system from time to time has by far the best opportunity of judging the extent of the change required in the controls. If the change required is then made through the intermediary of another operator, the extent of the change must be described by the first and interpreted by the second. If the correction is too great or too small, a period of hunting will occur which is detrimental to the performance of the unit. The ideal arrangement for centralized control would be to place in the hands of the operator in charge of the control panel a means of making his own corrections. He is in a better position to judge than another operator who merely receives an order to make a change. In some cases automatic instruments are available to eliminate the necessity of making manual corrections, but there are many controls which are preferably controlled by manual operation; clearly, some system of remote control from the board is a necessary link in the progress toward centralizing responsibility for one operation or one operator.

Remote control for still operation has been effected in the past by mechanical connections or hydraulic means and, to a lesser extent, electrical appliances have been resorted to for this purpose. Mechanical contrivances for producing motion at a distance are limited, owing to the fact that in many cases pipe lines, of necessity, must be diverted to within reach of the control board, or the board placed in a favorable position, in order to make the arrangement possible. In point of fact, this is often done much to the detriment of the location of the control panel.

The electrical and hydraulic devices which have been used heretofore have not been particularly well suited for adjustment, in most cases merely serving to open or close valves at a distance. The ideal control is evidently one in which the receiving mechanism will follow accurately the motion of the transmitter, in addition to which it is always desirable to have the resistance to motion felt on the transmitting end to be certain that undue force is not applied to the mechanism to be changed, thus avoiding possibility of breakage.

Bearing in mind the foregoing, it is apparent that a distinct possibility exists in the application of Selsyn motors to remote control of this character, since their action has fundamentally the characteristics desired, *viz.*, they are accurate and permit the resistance to motion to be felt in the transmitting end.

During the past few years tests have been made using Selsyn motors for remote indication and control with excellent results. To attempt to describe all of the possible uses would be quite impractical; therefore it seems best to illustrate their usefulness by describing only typical installations.

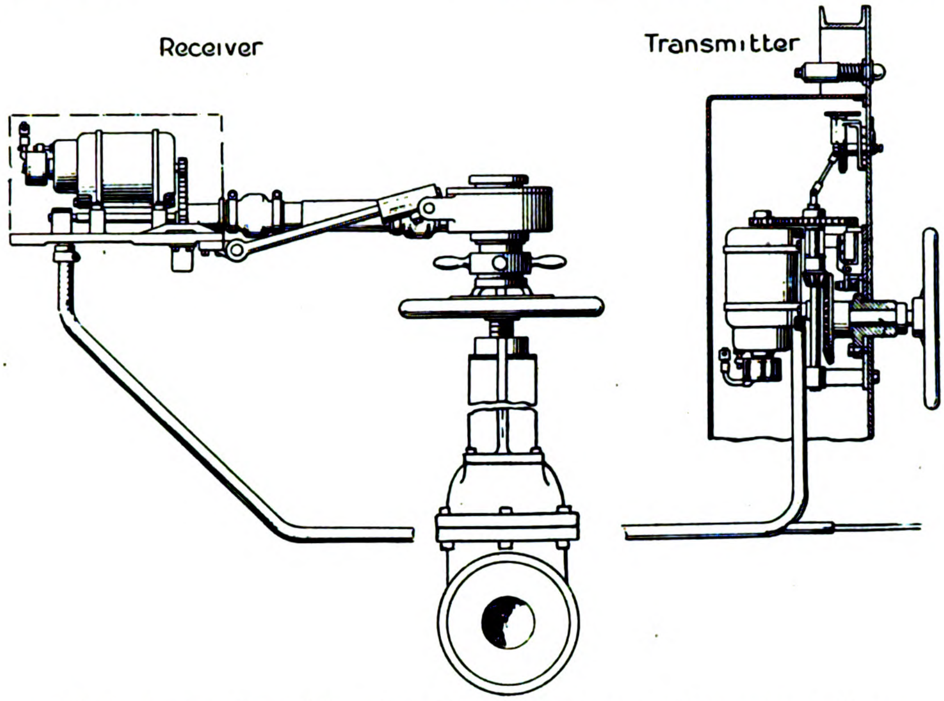


Fig. 1. Drawing of Transmitting and Receiving Selsyn Equipment for the Operation of a Valve

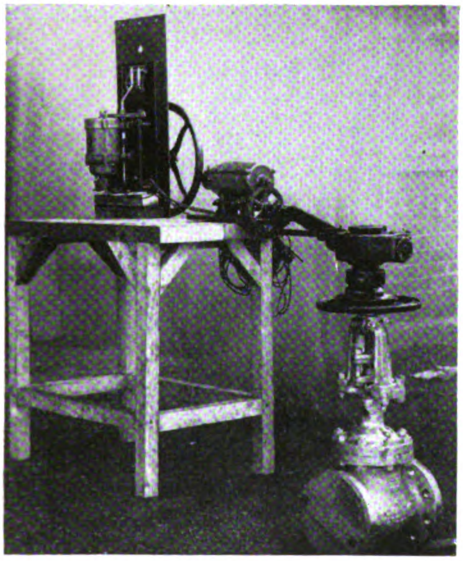


Fig. 2. An application of Selsyn Equipment, Showing the Indicating, Actuating, and Operating Mechanisms for Valve Operation

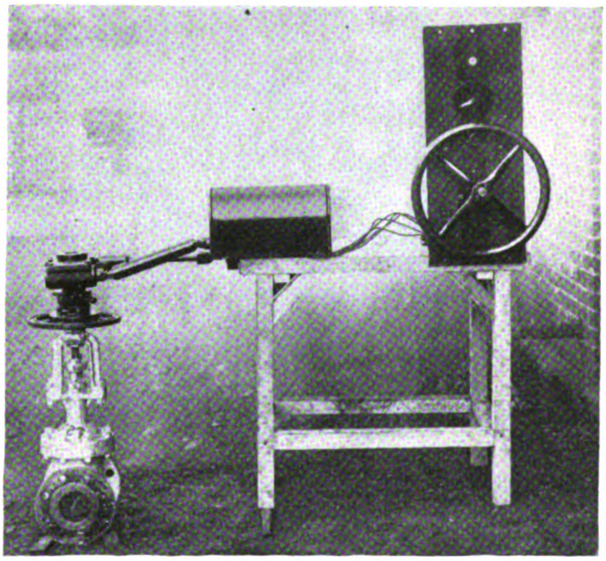


Fig. 3. Another View of the Selsyn Equipment of Fig. 2, Showing Front of Transmitting Panel and Flexible Connection to Valve

At present one of the widest fields for Selsyn motors exists in connection with a mechanism designed to control or adjust the setting of a valve at a distance. This arrangement, comprising a transmitting and receiving mechanism as applied to a valve, is shown in Fig. 1 and further illustrated in Figs. 2 and 3. The transmitting mechanism comprises a wheel which rotates the transmitting motor through a gearing and through which the control is effected. The rotating of the transmitting motor causes the rotation of the receiving motor, the motion of which is transmitted through a gearing to a shaft and thence to a worm gear which in turn is connected to a wheel on the valve stem. The worm gear mechanism is connected to the valve wheel by means of a clutch, half of which is clamped permanently to the spokes of the valve wheel, the other half being directly connected with the worm mechanism. A quick-detachable clutch is inserted between the wheel and the worm case so that the mechanism can be disconnected quickly and at will. It will be noted that the drive shaft from the receiving motor is flexible and that the mechanism can thus be applied to a wheel which is solidly mounted on the valve stem and which will rise and fall as the setting is changed. In addition to this, the worm gear is hollow; in the event that the mechanism is applied to a rising stem valve the stem can pass freely through the center of the worm.

The transmitting unit is made up in small panels roughly 30 in. by 16 in. which can be bolted through control panels or assembled in batteries. A pointer or indicator is connected with the motion of the transmitter wheel to denote the amount the system is turned, and a pilot light is incorporated in the unit to indicate when the circuits are energized.

The receiving mechanism can be applied to any type of valve or to effect any rotary motion desired. The power transmitted to the receiving mechanism is only that which is impressed on the transmitting wheel. Thus the resistance to motion can be gauged and the actual amount of correction observed on the wheel in the same manner as it would be observed in turning the valve itself. There is, of course, some loss in friction but this is comparatively small and ample power is provided to start the valve from a jammed "full closed" position when necessary.

The motors themselves, which can be likened to rotary solenoids, have of course a limited amount of torque which they can transmit without having the phase broken down. This torque can be amplified, however, by merely gearing up the transmitting motor and the gearing down the receiving motor. Thus the power is transmitted at low torque and high speed and the extent to which the motors are out of phase becomes relatively unimportant, since this amount which may aggregate five or ten degrees, is reduced in proportion to the gear ratio. Thus, with a gearing of 100 to 1 on the transmitter and receiver, the valve wheel would move the same number of turns as the transmitting wheel; one turn of the transmitting wheel would cause 100 turns of the transmitting motor and, correspondingly, 100 turns on the receiving motor,

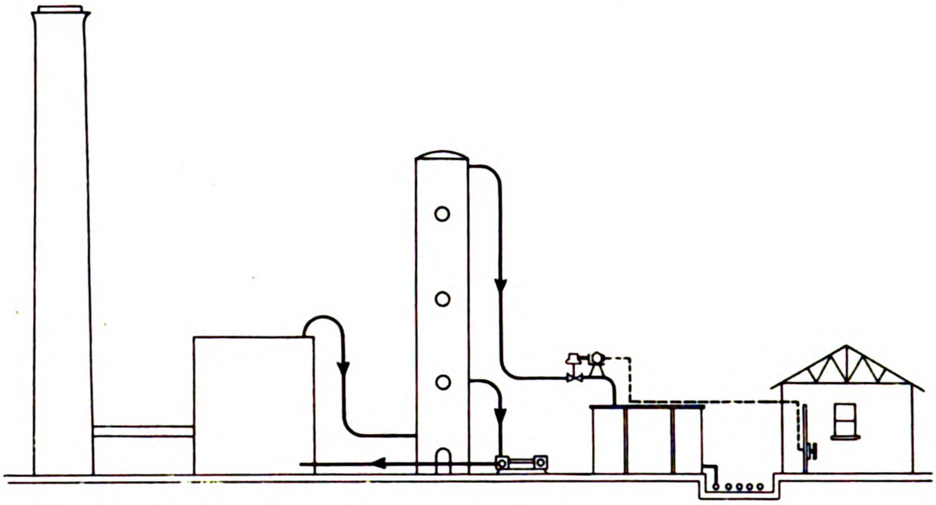


Fig. 4. Diagram of Selsyn Equipment Application for Pressure Control Between the Tower and Condenser of an Oil-cracking Unit

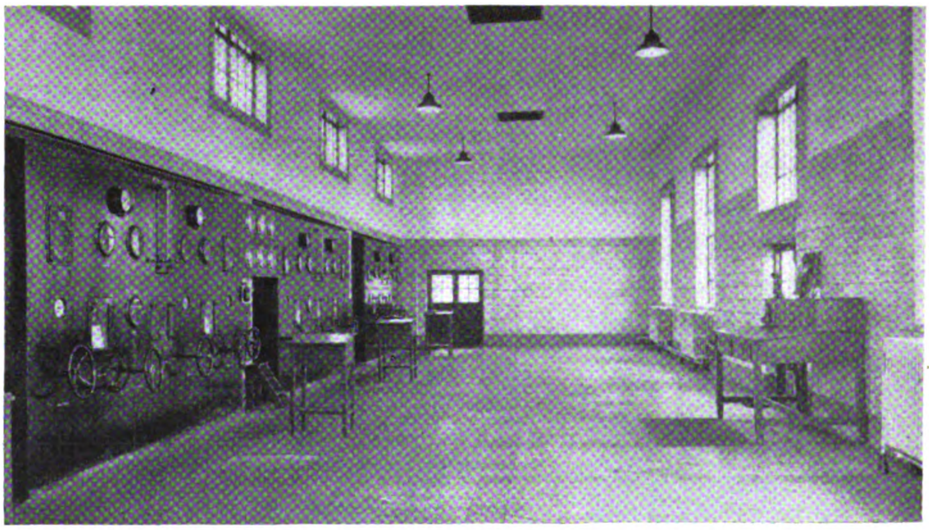


Fig. 5. A Control Room, Showing the Location of Transmitting Equipment

also geared down 100 to 1, or one turn on the valve wheel. Furthermore, the extent to which the motors were out of phase during this process would be 100 times greater than the extent to which the transmitting wheel and valve wheel would be out of phase. If we assume a 10-deg. change in phase of the motor shafts, the transmitting motor and valve wheel would be only one-tenth of a degree out of phase which for all practical purposes is negligible. The mechanisms are made usually to transmit from 150 to 200 ft-lb., which appears to be ample to turn any valve mechanism. They also can be made to operate in any ratio desired to obtain close control; and, by changing the gear ratio, it would be possible to have four turns of the transmitting wheel to one turn of the valve in the event a close regulation is desired or a heavy valve is to be turned.

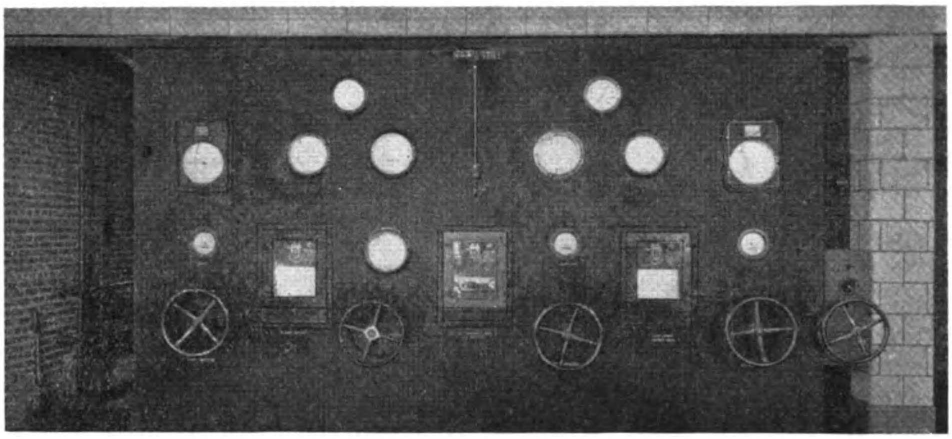


Fig. 6. A Typical Instrument Board Containing Feed and Temperature Control and Recording Units

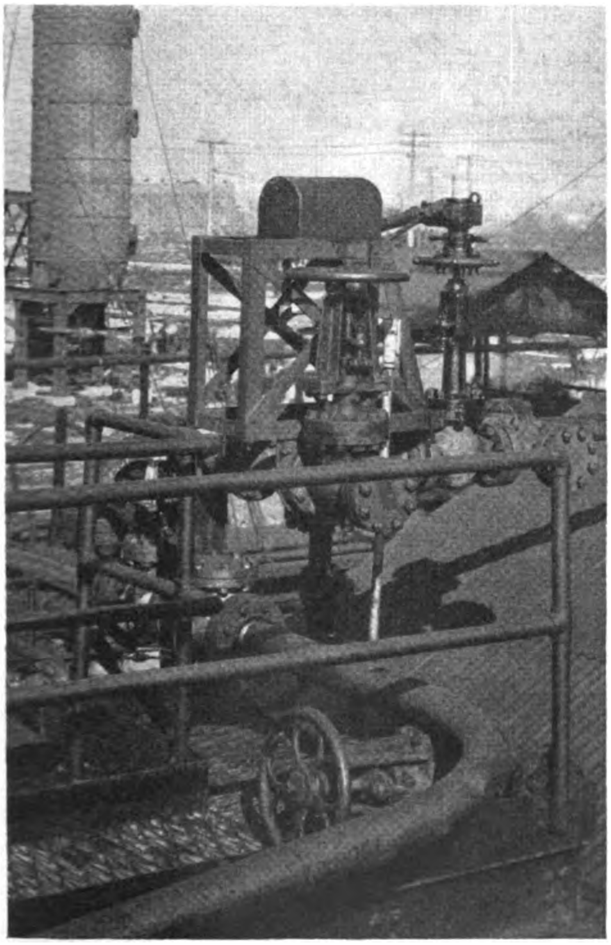


Fig. 7. The Receiving Equipment for Valve Operation in Pressure Control of the Cracking Process

Two applications of this mechanism are illustrated. The first, Fig. 4, shows a diagrammatic layout for the control of pressure between the tower and condenser of a cracking unit. The transmitting mechanism (Fig. 5) is located on the instrument board (Fig. 6), while the receiving mechanism (Fig. 7) is connected to the release pressure valve on the condenser. It is interesting to note that with this device the pressure required in the process is maintained and correctly regulated. This control was formerly effected by having the valve manually operated near the tower by the pump man. As long as the control of pressure was not affected by the control-board operator and maintained constant by the pump man, it was impossible for the control board man to determine whether the conditions of the process were balanced and the unit operating normally, since any tendency to decrease or increase in pressure did not manifest itself on the board. By placing the control of pressure on the control panel any indication of unbalance in the system, due for instance to excessive temperatures, unsuitablecharging rate, or other factor, shows up almost immediately by a change in pressure. Since the control-board operator knows what corrections he has made, any change in the operating pressure leads him first to scrutinize other conditions before resetting the release valve, and under these circumstances he has gained not only a more accurate control of his pressure but a very useful indication on the general operating condition of his equipment, which is reflected in more economical operation.

Another illustration of the application of this mechanism is shown in Fig. 8, where a control of the quality of cuts on a large fractionating tower is made directly from the receiving house. In this instance a tower approximately 150 ft. high is equipped with internal valves at various levels, the adjustment of which determines the quality of the side streams taken off the tower and inspected in the receiving house. In the event it is desired to change the quality of a side stream, the tower controls are moved directly by the operator whose duty it is to maintain the required quality of distillate passing through the look boxes, which he can do by merely moving the control wheel on the transmitter located within a few feet of the look box. The mechanism not only eliminates the necessity of climbing the tower to accomplish this but

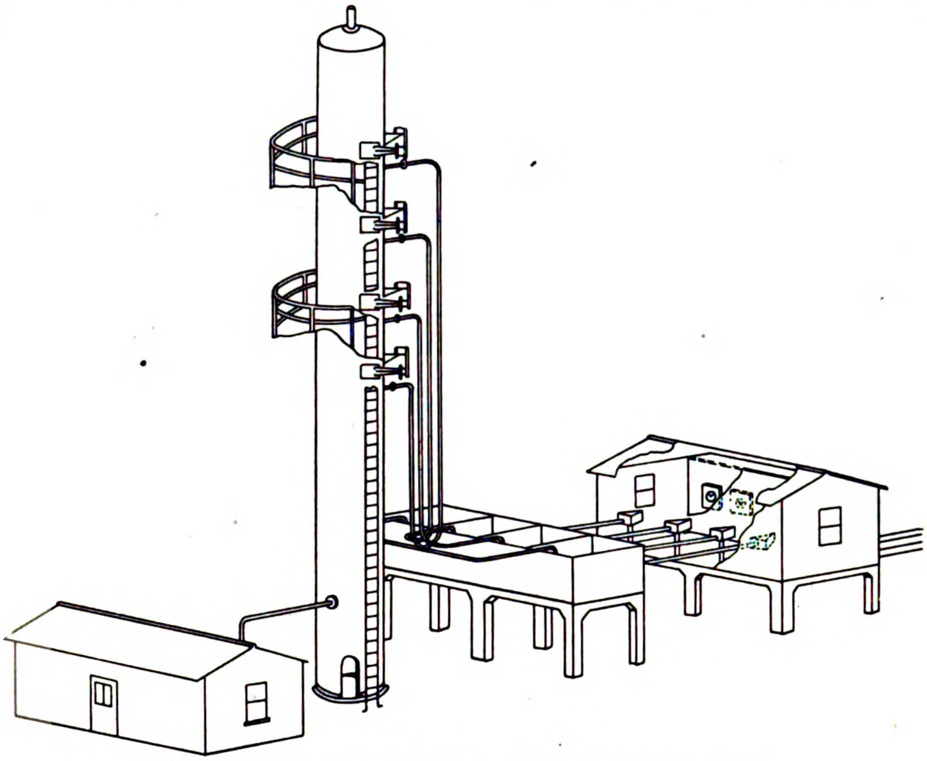


Fig. 8. Diagram of an Application for the Control of the Quality of Cuts on a Large Fractionating Tower

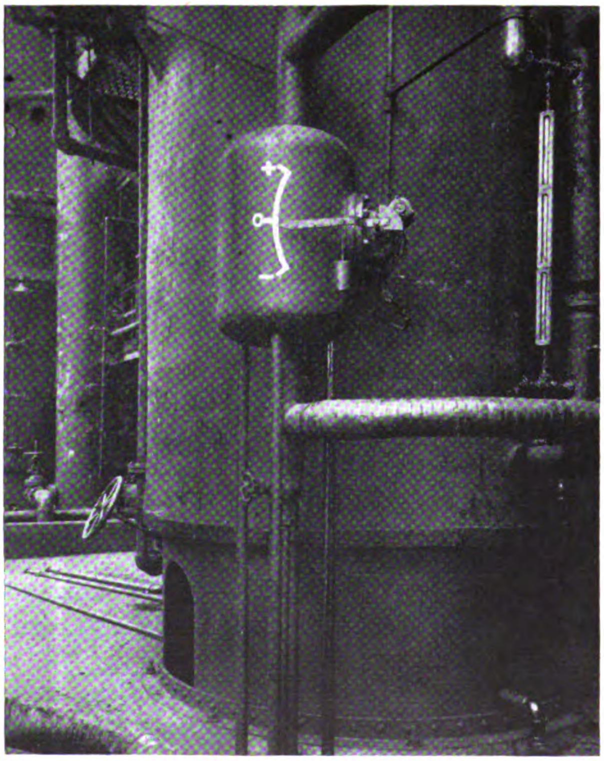


Fig. 9. Transmitting Unit in the Control of a Pump Holding the Level in a Fractionating Tower

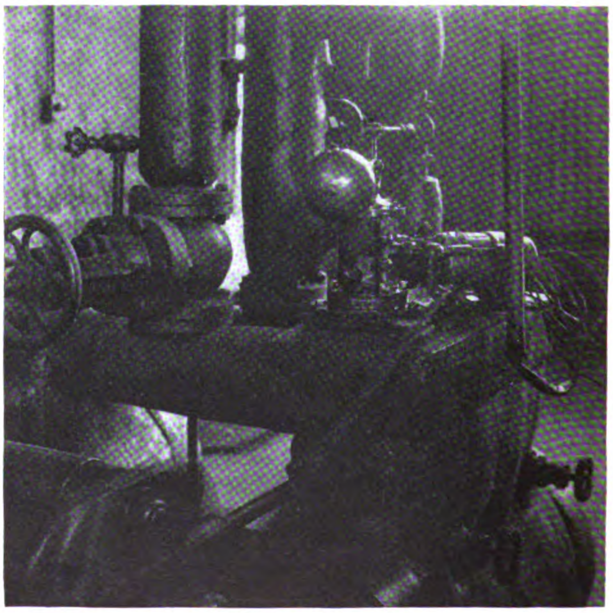


Fig. 10. The Receiving Unit in the Pump Control for Holding Level in a Fractionating Tower

reduces the error in corrections by making it unnecessary for a second operator to interpret the orders of the man in charge of the house to effect certain changes. It is true that it might be possible to do this mechanically, but considering the height of the tower, the clumsiness of the mechanism necessary to apply power through rods and gears, and also the fact that it would be hardly possible even then to bring this control into the house, the Selsyn motors here serve a particularly useful purpose.

Aside from the remote control of valves, Selsyn motors have also been used to transmit accurately the motion of certain parts of equipment, such as floats, and this motion can be utilized to effect automatic control. Fig. 9 shows an arrangement to control the operation of a pump in relation to holding a level in a fractionating tower. A small chamber containing a float is attached to the tower, and the float, rising or falling, rotates a shaft which in turn is connected with a transmitting Selsyn motor. The receiving motor (Fig. 10) is attached to the adjustment key of a Mason-type speed governor which requires very little power to turn and which accurately controls the speed of the pump. Thus, as the level rises, the governor will be reset for a greater number of strokes per minute and *vice versa*. By arranging the float on a very small arm, which is possible in view of the fact that practically no power need be transmitted, departures from the normal level will cause an increasing change in angularity of the shaft connected with the transmitting motor. This proportional correction balances the speed of the pump and eliminates the hunting effect which usually makes this type of control inoperative.

Another application of the Selsyn motor is that in Figs. 11 and 12, which show its application to the control of the speed of a pump at a distance from the control board. In this case the transmitting motor is attached to a hand wheel on the board while the receiver actuates the setting of the governing mechanism. A mercoid switch indicates the strokes of the pump on the control board and if the operator desires to change the speed of the pump, all that is required is that the hand wheel shall be turned in one direction or the other which takes effect immediately on the governor and in turn on the pump.

The foregoing illustrations are typical of useful applications of Selsyn motors in refinery equipment and it is felt that their characteristics are such that their use for this class of work is almost unlimited. Such installations not only furnish accurate means for indication and control, but permit much greater freedom of design in pipe work and permit placing the control panel in a safe location where it may be also free from the dirt which comes from periodic cleaning of the stills. At the same time no disadvantage is experienced from the remote location of valves and control points which might be beyond reach unless special provision were made to relocate them specifically for the purpose of control.

In view of the success which has been had with the use of Selsyn motors here briefly described, and the demand which has been created by the installations already made, the Brown Instrument Company of Philadelphia (Pa.) has undertaken the construction and sale of certain remote control equipment particularly applicable to the oil industry; and it is expected that in the course of the next few months such equipment will be available commercially and become a standardized device for refinery use.

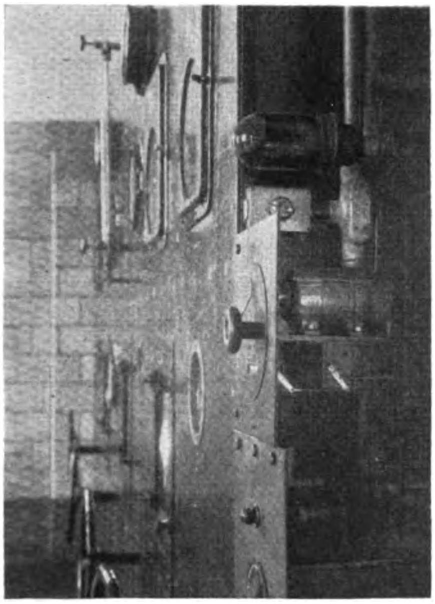


Fig. 11. The Transmitting Unit for the Remote Control of Pump Speed

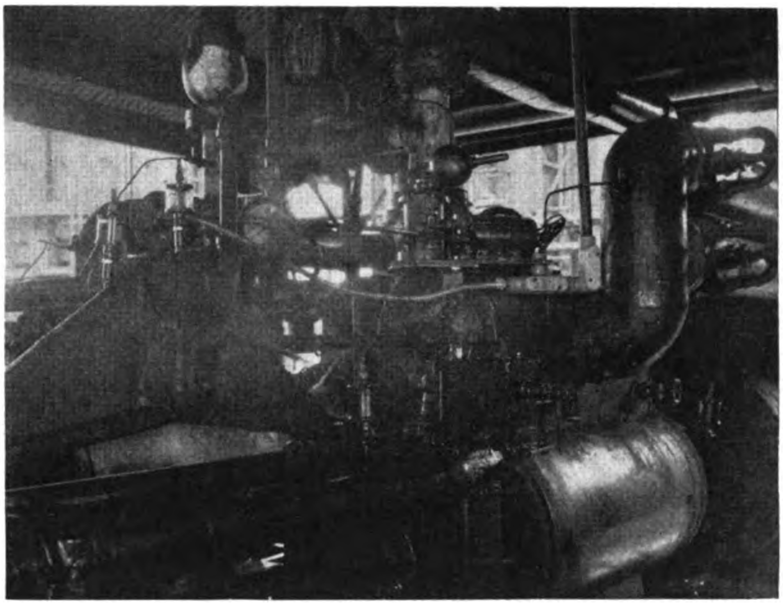


Fig. 12. The Receiving Unit, Actuating the Governor Mechanism in Remote Control of Pump Speed

Recent Improvements in High-voltage Insulator Design

Diagnosis of Insulator Faults—Complex Conditions Necessitate Extreme Care in Determining Effect of a Variable Factor—Contact Surface with Hardware a Vulnerable Point—Reglazing of Roughened Surface Increases Mechanical Strength and Decreases Electrical Failures

By **D. H. ROWLAND**
Research Engineer, Locke Insulator Corporation

IT can be said without reservation that trouble with high-tension insulators has decreased greatly in the last few years.

There is little doubt that many of the theories advanced to explain the failures of porcelain insulators in the past were decidedly erroneous. No part of the insulator and no feature of design and assembly but were at some time or other, by some one or other, credited with the failures. Unfortunately a general acceptance of some of the explanations retarded, rather than aided, the correction of the fault. Specifications were frequently drawn up to lay such stress on one particular characteristic that other characteristics had to be neglected to produce insulators capable of meeting the stressed requirement.

It is now conceded that in the design of an insulator a compromise must be made between several factors if satisfactory service life is to be obtained. It is also definitely recognized that many of the reasons previously advanced to explain porcelain failures were only partially correct, and that the improvement in service came from the eradication of certain design or assembly features, from improved body composition, and the development of more exact methods of factory control. Only a few years ago it was impossible to run unassembled porcelain disks through more than two or three cycles from boiling water to ice water without considerable breakage. Today such failures are practically unknown.

The improvements which are evident in modern high-tension insulators were not the result of haphazard experimenting or the following of some fanciful theory. A great deal of painstaking research work in ceramics was essential and, owing to the highly specialized field of electrical porcelain, little assistance could be obtained from the ordinary ceramic laboratory. Practically all the work which has had any bearing on insulator improvement has been done in the research laboratories of insulator manufacturers.

The research laboratory of the Locke Insulator Corporation has been constantly employed for many years in establishing the characteristics of porcelain bodies containing different proportions of clay, feldspar, and flint. While this work has resulted in decided improvements of the actual porcelain body, probably one of the most outstanding developments from this research has been the discovery of the unexpected importance of a certain factor in the strength of porcelain.

In order to determine the strengths of different porcelains, rods having a diameter of 1⅛ in. were made up and broken transversely between supports 5½ in. apart. In addition to revealing which body had the greatest strength, this series of tests also showed that a wide variation in strength with the same body might be expected to follow variations in the character of the glaze, despite the fact that the thickness of this coating was only about 0.006 in.

Some of the results of this work were published in the March 1929 issue of this magazine under the title "The Influence of Glaze on Insulator Strength." Table I, which is here reprinted from the former article, gives an idea of the variation introduced by changing the glaze. The strengths shown in the different columns are for rods of identical porcelain coated with glazes of various chemical compositions.

The chief difficulty experienced in making tests on ceramic materials is that of eliminating all extraneous factors so that the results obtained may be known to result from the variable under consideration. For instance, in comparing changes in the strength of suspension insulators with variations in some point of design, the greatest care must be exercised to prevent differences in drying conditions, fluctuation in firing, or any other variation, however slight, in the handling of the insulators from raw material to time of test. When testing porcelain rods, for example, all test specimens were carried through the plant at the same time and fired intermingled in the same saggers. With

TABLE I

Group	1 Unglazed	2 Glazed	3 Glazed	4 Glazed	5 Glazed	6 Glazed	7 Glazed	8 Bad-fitting Glaze
Average strength in lb.	1061	1016	1290	1299	1716	989	957	384
Per cent mean variation	4.6	3.6	9.35	8.9	3.8	6.25	4.36	5.5

insulators, the problem becomes more complex. Not only must the ware be carefully carried through the making and firing processes, but the cement and selection of the hardware parts must be controlled with equal care.

In the tests on suspension insulators which are described in this article, the clay was taken from the same press, run through the same pug mill, and the molds filled in strict rotation in an identical manner. As the molds containing the plastic clay passed through the machine, they were given consecutive numbers which they carried through all the subsequent processes. The ware was placed in the drying carts and later in the kilns so that the odd and even numbered insulators were equally distributed. The variable under study was limited to the odd-numbered units. The other group, comprising the even numbers, was tested to check against these results, it being assumed that no matter what extraneous factors entered into the making of the total number of insulators their influence on each lot would be approximately the same.

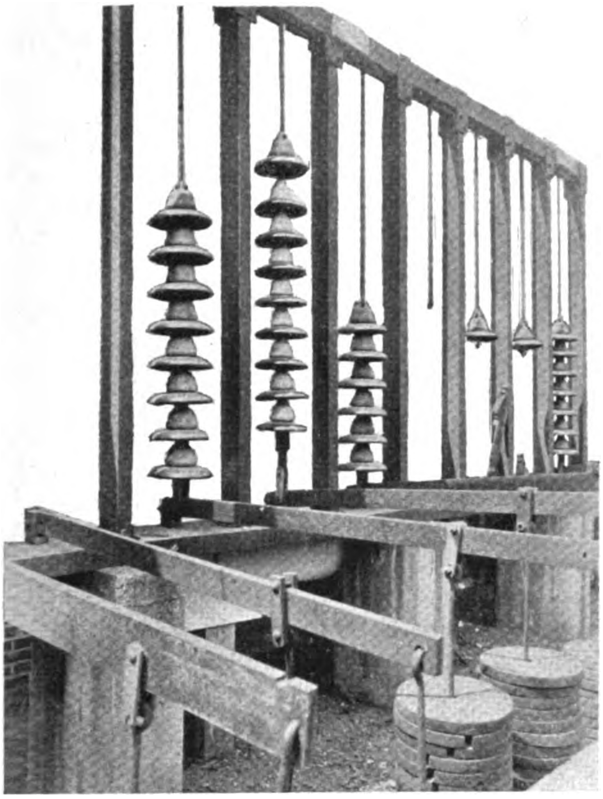


Fig. 1. A String of Suspension Insulators in a Test Frame to Determine Their Mechanical and Dielectric Strengths

The factor under consideration was the treatment of the porcelain surface which comes in contact with the cement used for attaching the hardware. It has been standard practice for some years to obtain this cement grip by the use of fired porcelain ground so that the particles are about 1/32nd of an inch in diameter. This porcelain sand, or grog, is stuck to the green ware by a mixture of glue and glaze. As the ware goes through the kiln, the glue burns out and the glaze melts and attaches the sand to the surface of the ware. The glaze used in the tests described was almost as strong as that used on the rods tabulated in Column 5 of Table I.

A preliminary strength test was made on porcelain test rods having surfaces which were sanded in the usual manner. It was immediately found that the presence of the sand particles so decreased the strength of the rods that they were practically no stronger than unglazed porcelain. Following this, similar rods were prepared with the difference that after sanding the rods were again dipped in glaze. As the result of a large number of tests, it was found that this treatment raised the strength of the rods approximately 20 per cent above those sanded in the usual manner.

In an effort to determine what bearing this had on the strength of suspension insulators, the group of units that have been described was made up. Half of these insulators had the regular uncoated sanded surfaces and the remainder had the sanded surface reglazed. For the purposes of these tests a longer loading schedule than that laid down in the A.I.E.E. specifications was adopted, as it was thought that the results would be a better criterion of what could be expected in service. The units were connected together in strings, the insulators to be compared being alternated. The strings were then hung in a frame arranged with levers and weights by which a tension load could be applied. Fig. 1 shows a string on the frame under load. The initial load in this case was 10,000 lb., and each morning an additional 1,000 lb. was added and each separate disk immediately flashed over at 60 cycles.

The results of the tests were decidedly in favor of the units having the reglazed sand surfaces; but in order to check this result a second trial was made in exactly the same manner. Again the data showed conclusively that the treatment of the sand in the manner described was an essential factor in the performance of the insulator. The importance of running the test units through the plant in one group is made apparent by the results obtained in these two trials. While the difference between the treated and the untreated insulators is quite evident in each case, it is very plainly seen that it would have been difficult to have drawn absolute conclusions as to the merit of the treatment had the untreated insulators of one group been tested against the treated insulators of the other group. Fig 2(a) shows the results of the first trial and Fig. 2(b) the results of the second. The tension loads on the string are shown by the ordinates and the time of application by the abscissas. Along the curves are noted certain numbers and letters such as *2S* and *3R*. The former symbol indicates the electrical failure of two standard units while the latter represents the failure of three reglazed units.

The areas under the curves represent the number of days multiplied by the average load carried during the period by each insulator. By adding up these time-load areas for each group of insulators and dividing by the number of units under test, a figure is obtained which is an indication of the "average duty" performed by the insulator in question. The rectangles shown above the curves were obtained in this way, the minimum values at electrical failure being given just above the rectangles.

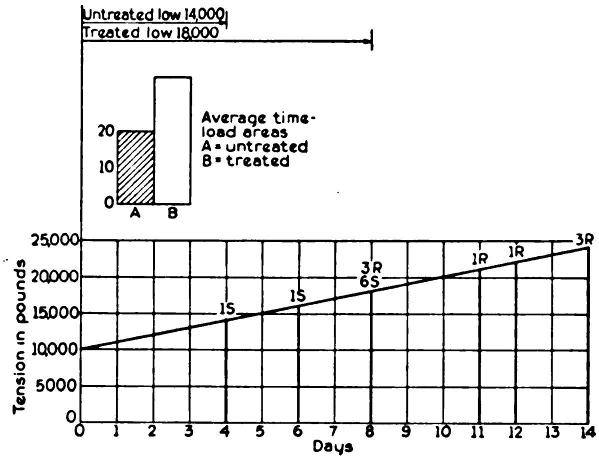


Fig. 2(a)

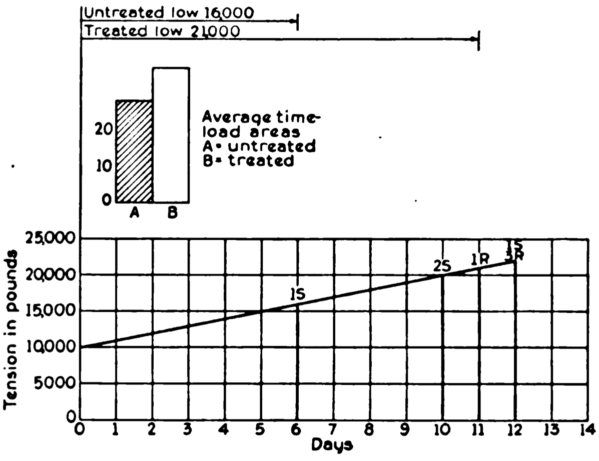


Fig. 2(b)

Fig. 2. Record of Two Series of Tests Made to Determine the Extent of the Improvement in the Performance of Insulators Resulting from the Reglazing Process Described in This Article.

Regardless of all other factors of design or manufacture, this one ceramic detail goes a long way toward improving the performance and lengthening the life of the suspension unit. Figs. 3 and 4 show sketches of cross-sections of the ordinary type and the reglazed type of sanded surfaces. Examination of Fig. 3(a) shows that where the sand particles touch, a definite angle is formed. When it is considered that a piece of porcelain with glaze and sand applied is really a solid piece of glass-like material, as shown in Fig. 3(b), it can readily be seen that each of these angles represents an incipient crack which when stress is applied in a certain direction will tend to creep through the entire mass.

This is actually the case and accounts for the low values obtained in breaking sanded rods. When a coating of glaze is applied over the surface of the sand, a minute fillet is introduced between the sand particles and the depressions are therefore wavy (Fig. 4b) instead of angular (Fig. 3b). In addition to this, the reglazing considerably strengthens the bond between the individual particles and the surface. Taken in conjunction, these two effects not only result in increased strength but in greater uniformity and consequently lengthened life.

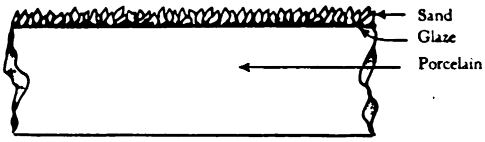


Fig. 3(a)

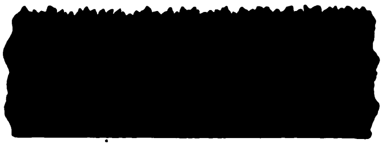


Fig. 3(b)

Fig. 3. Cross-sectional Sketches of a Piece of Porcelain Having a Sanded Surface Glazed in the Usual Manner. Note the acute-angle depressions

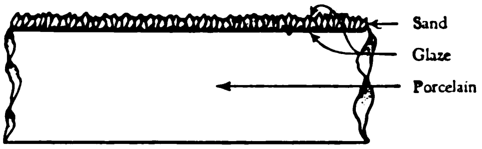


Fig. 4(a)

Fig. 4(b)

Fig. 4. Sketches Similar to Those in Fig. 3 but of a Porcelain Specimen Having a Sanded Surface That Has Been Reglazed. The surface retains the rough characteristics necessary for a cementing attachment to insulator hardware but the sharp depressions that are potential cracks have been eliminated

Conclusions

The electrical failure of a high-tension porcelain insulator as a general rule starts as a minute mechanical crack in the surface of the dielectric. Owing to the non-ductility of porcelain, such a crack will slowly but surely work through the material because of changes in external loading or temperature variations with consequent expansion and contraction of the porcelain. All cracks must start at the surface and therefore if the surface is strengthened in a manner which prevents the starting of cracks a great deal has been done to prevent a progressive failure. What in the past has been referred to as deterioration of porcelain has no doubt in many cases been due to a progressive crack caused by weak surface conditions.

In order to obtain the proper surface strengths there are two primary factors which must be taken care of:

(1). The glaze used must fit the body in order to develop the maximum surface strength.

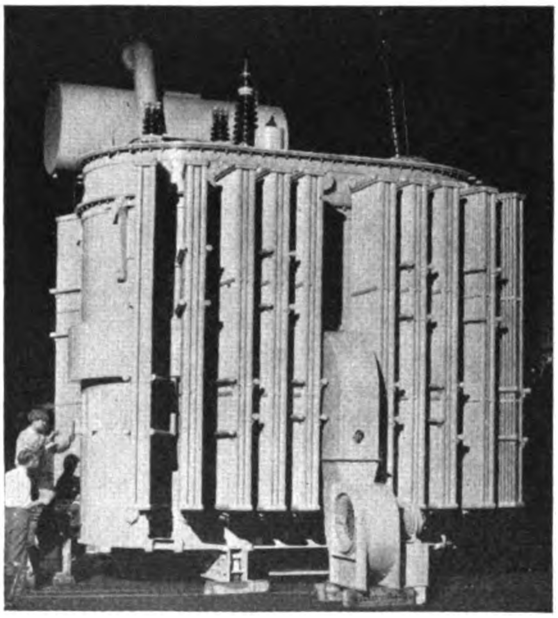
(2). The physical shape of any roughening that is applied to the surface of the porcelain must be such that it does not tend to form angles which in turn will develop into cracks.

The tests that have been made up to the present time have been conducted on suspension insulators only. It is evident however that the condition of the surface inside the tops of pin-type insulators, or under the caps of pedestal switch insulators, is of equal importance. This is especially true where the units are subject to vibration.

Research on this subject is by no means completed and it is confidently expected that developments in the near future will still further improve the high-voltage insulator.

Non-resonating Transformers for California

Three 40,000-kv-a. 220,000-volt transformers of the new non-resonating type developed by the General Electric Company have been installed at the Long Beach No. 3 generating station of the Southern California Edison Company. Owing to the non-resonating feature, electrical stresses caused by over-voltage surges are greatly reduced throughout the entire winding, permitting higher factors of safety than have ever been obtained before.



The insulation of these transformers is coördinated with that of the rest of the transmission system; that is, the transformers are designed to be electrically stronger than the insulators that carry the 220,000-volt transmission line. Thus, if lightning should strike the line or very high voltage surges should be induced in the line by a nearby stroke, the line insulators will be the first to flash over and thus tend to relieve the abnormal voltage stress.

The transformers are near the ocean, subjected to salt fog which leaves conducting deposits on the high-voltage bushings. The bushings are therefore specially designed to give an extra long creepage distance between live parts and the tank, so that they can be washed periodically with a spray of water without removing the transformers from service. Because of the unusual design the bushing is supplied with an arcing horn to form a gap by which the normal dry flashover value of the bushing is maintained.

Each transformer occupies a floor space of about 18 by 20 ft. The height over the cover is nearly 18 ft., and over the high-voltage bushings is 28 ft. The total weight, including 14,000 gal. of oil, is about 136 tons and without oil is 84 tons.

In spite of their size, no difficulties were encountered in their transportation and installation. They were shipped from Pittsfield to Los Angeles in 13 days, each assembled in its own tank and loaded on a standard transformer car. They were made ready for installation, on arrival, by merely refilling the transformer with oil and reassembling certain parts which were removed prior to shipment to meet railroad clearances. Each tank was filled with nitrogen gas during shipment to exclude air and moisture.

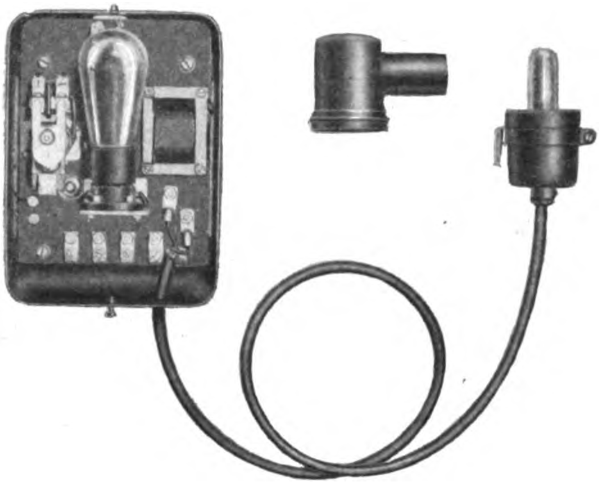
New Device Uses Light to Control Machinery

The interruption of a beam of light controls the operation of industrial machinery and other devices by utilizing a new control device, the photo-electric relay. The relay is essentially a vacuum-tube device, and uses both the photo-electric tube and the Pliotron tube. Many industrial and other operations in which a change of light is involved can be controlled by the new relay. In addition, operations which can be arranged to cause a change of light can be so controlled. A machine, for example, which travels in a certain direction for a certain distance and is then stopped or reversed is a typical application. When the traveling mechanism reaches its limit, it would interrupt a beam of light falling on the photo-electric tube and thus cause the control device to function.

Another example of application would be in counting bags of material, boxes, etc., where mass production is involved. As each item passes through the essential beam of light, it would cause the photo-electric relay to operate and actuate a magnetic counter. Vehicles passing a definite point can be counted in like manner. An example of the latter application is found in the Holland Tunnel where automobiles are counted by the photo-electric relay.

A third type of application would be in the sorting of packages according to size, shape, or reflecting power. Other examples would be stopping a paper machine when the paper breaks, aligning the paper on the rolls of the same machine, turning electric signs or signals on or off depending on the intensity of the outside light, deflecting packages on conveyors, and operating bag-piling mechanisms.

The use of the photo-electric relay to control lamps or illuminated signs according to the intensity of daylight is an interesting one. In an office or factory building it is always desirable to have no less than a certain minimum intensity of light for the workers. During the day time, when the daylight intensity is high, no artificial lighting is needed. By using the new relay, the artificial lights can be turned on automatically when the daylight intensity falls below the predetermined minimum.



The Photo-electric Relay (with Its Cover Removed) Showing the Control Box, Connecting Cable, and the Photo-electric Tube Pick-up Unit and Its Case

The new relay is designed for use in controlling an electric circuit in response to an increase or decrease in the amount of light falling on the photo-electric tube. It possesses the following advantages:

(1). It operates without shock or resistance to the progress or movement of the object which actuates it, or without impairing the accuracy of delicate mechanisms.

(2). It can be located remotely from the equipment controlled, thus permitting mounting in small spaces around automatic machinery.

(3). It is adjustable in sensitivity.

(4). It can be used outdoors by mounting in a watertight enclosing case.

(5). It is easily installed, and its operation is easily adjusted or changed.

(6). It can be operated at high speeds, 100 times a minute being an approximate maximum.

For some applications it may be necessary to select a particular type of light source and optical accessories, but for many cases the source may be a domestic Mazda lamp with or without a simple reflector and shield.

The standard electric supply for the relay is 110/120-volt 60-cycle alternating current. The device may however be built for other frequencies or voltages, and also for operation where only direct current is available.

The operation of the relay is as follows: With a voltage of proper polarity and magnitude applied between the two elements of the photo-electric tube, the current it passes is proportional to the amount of light shining on it. This current (of the order of a few micro-amperes) is amplified by a Pliotron tube. The sensitive relay[*] is connected in the plate circuit and is energized or deënergized in accordance with the amount of light on the photo-electric tube. The contacts of the relay control the coil circuit of the contactor. When the relay in the plate circuit of the amplifier is energized, it will first open its normally-closed contacts and then close the normally-open contacts. This relay, therefore, either makes or breaks the coil circuits of the contactor depending on how it is connected.

When the contactor is deënergized approximately ten watts is required by the device, and when the contactor is energized approximately 30 watts is required.

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[*] Identified by the trade designation CR7505-A1.

Joints in Heavy Electrical Conductors

Preparation of Contact Surfaces—Effects of Pressure—Maintenance of Bolted and Clamped Joints—Design of Joints—Preservation of Contacts

By EMIL G. BERN and W. SPECHT
Switchgear Engineering Department, Philadelphia Works,
General Electric Company

THE usual rules of maximum current density for a given cross-section, or the more rational ones of maximum temperature rise, have generally behind them the important purpose of maintaining the joints or contacts in perfect condition. Aside from the question of potential drop in the conductor, there might appear to be very little advantage in limiting the temperature rise to the customary 30 deg. C. over an ambient temperature of 40 deg. C. However, considering the electrical contacts that may be exposed to a higher temperature by passage of heat from the conductor, it becomes very important to limit the total temperature in the conductor. For this reason, the temperature limitations just mentioned have been imposed on switching equipments.

In many cases serious trouble with heating of joints or contacts has apparently been cured by reinforcing the cross-section of the conductors. This cure may have been effective, although unnecessarily costly. Simpler means might have been found if the root of the trouble had been discovered. For this reason the following notes have been made as timely suggestions on joints in heavy electrical conductors.

Contact Surfaces

The ideal result in such joints would no doubt be obtained with contact surfaces ground perfectly smooth and flat, but as this is not practicable a draw-file finish, or a finish produced on a flat wheel covered with emery paper, is the next best. The advantage of a draw-file finish lies in its almost infinite number of minute contact points which engage under a moderate contact pressure, and at the same time provide a seal against entrance of any corrosive media. Between such surfaces it is customary to spread a thin layer of vaseline, oil paint, or similar substance which will seal any minute openings against the entrance of oxidizing fumes or air. The small scratches or furrows produced by this finish give an opportunity for escape of the surplus filler material, thus resulting in a more intimate joint at moderate pressure. It is very important during the finishing operation to guard against incipient oxidation by avoiding carefully any accidental touching of the contact surfaces with the fingers or hands. For this reason contact surfaces are frequently prepared under a film of oil or vaseline. This operation becomes especially important when dealing with aluminum, which takes on an insulating oxide much more quickly than copper.

It should be borne in mind that oxidation of copper, which even in ordinary air and in room temperature is very noticeable, becomes a serious matter in temperatures above about 70 deg. C. For instance, resistance measurements taken before and after exposing a clean contact joint to a temperature of 90 deg. C. for two hours indicated that the contact resistance had increased sixty times. A comparatively insignificant spot of oxidation on a contact surface may initiate a local heating of rapidly accelerating proportions.

In all good designs of buses and connections for heavy currents, the number of contact surfaces in series is held to the utmost minimum. Lap joints, instead of butt joints with splicing bars, are preferred wherever practicable.

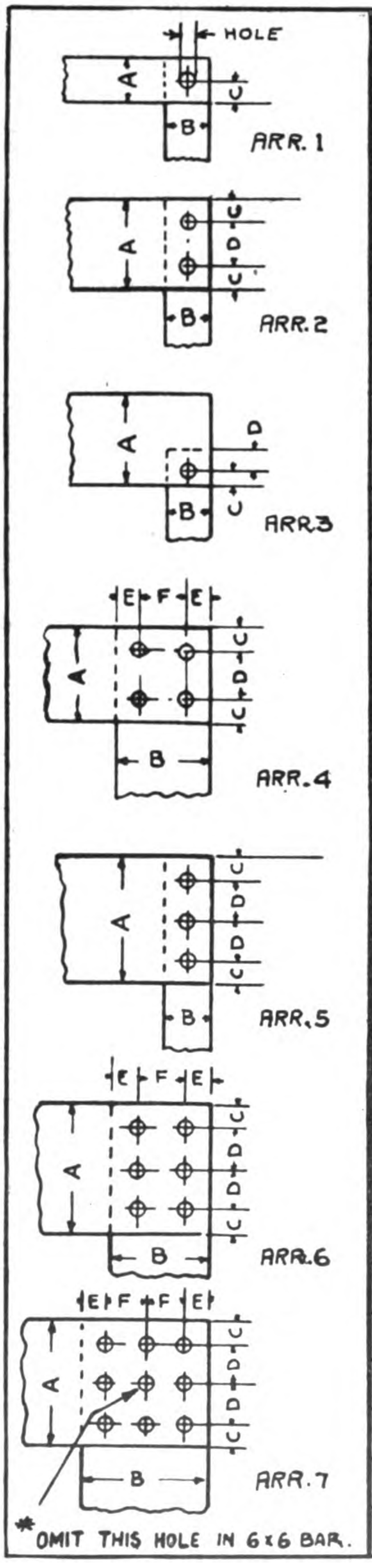
Contact Pressure

For contact surfaces in equal condition, the conductivity of the contact may be stated to be proportional to the pressure applied, within ordinary practical limits of bolted or clamped joints.

The size of the contact area is of less importance than is the total pressure on the contact. It is readily seen that the pressure per unit area increases with the reduction in size of the contact surface. For lower total pressures the smaller contact surfaces, that approach point or line contacts, have an advantage. However, it must not be forgotten that the larger surface offers a longer and more difficult path for the entrance of corroding fumes or air.

These rules apply under general conditions, but are governed by other factors of quite far-reaching nature.

Where a conductor is exposed to a wide range in temperature, a corresponding increase and diminution takes place in the thickness of the bolted or clamped contact varying in magnitude with the temperature expansion coefficient of the material. With the ordinary contact construction used in the splicing of conductors consisting of several laminations, the interspersed laminated joints multiply this variation in thickness very rapidly. Unfortunately the pressure is usually applied by one or more steel bolts of lower temperature coefficient than the material of the conductor; and to augment this problem the bolts, as a rule, are not heated by the current in the conductor in the same manner as the conductor itself. Therefore, there is a pronounced tendency for the joint to open slightly or to relieve the pressure with the reduction in temperature of the conductor. It is evident that the more intense pressures on such joints have a tendency to mushroom the line or point formations so that a line or point contact is no longer maintained the next time the joint expands. For this reason the line or point contact characteristics give proportionately better efficiency at lower pressure. However, at still higher pressures, yet within the elastic limit of the bolts, the mushrooming process has been carried to its limit, the particles of one surface have formed themselves to a closer fit with the particles of the opposite surface, and in this manner a more perfect union has been obtained with the line or point contact. This



BARS A	BARS B	ARR.	C	D	E	F	SIZE OF HOLE	BOLTS
1	1	1	1/2				15/32	3/8
1 1/2	1	1	3/4				15/32	3/8
1 1/2	1 1/2	1	3/4				5/8	1/2
2	1	1	1				15/32	3/8
2	1 1/2	1	1				5/8	1/2
2	2	1	1				5/8	1/2
2 1/2	1	2	1/2	1 1/2			15/32	3/8
2 1/2	1 1/2	2	1/2	1 1/2			15/32	3/8
2 1/2	2	2	1/2	1 1/2			15/32	3/8
2 1/2	2 1/2	4	1/2	1 1/2	1/2	1 1/2	15/32	3/8
3	1	2	5/8	1 3/4			15/32	3/8
3	1 1/2	2	5/8	1 3/4			5/8	1/2
3	2	2	5/8	1 3/4			5/8	1/2
3	2 1/2	4	5/8	1 3/4	1/2	1 1/2	15/32	3/8
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4	1	3	1 1/8	3/4			15/32	3/8
4	1 1/2	2	1 1/8	1 3/4			5/8	1/2
4	2	2	1 1/8	1 3/4			5/8	1/2
4	2 1/2	4	1 1/8	1 3/4	1/2	1 1/2	15/32	3/8
4	3	4	1 1/8	1 3/4	5/8	1 3/4	5/8	1/2
4	4	4	1 1/8	1 3/4	1 1/8	1 3/4	5/8	1/2
5	1	3	1 1/4	3/4			15/32	3/8
5	1 1/2	2	1 1/4	2 1/2			5/8	1/2
5	2	2	1 1/4	2 1/2			5/8	1/2
5	2 1/2	4	1 1/4	2 1/2	1/2	1 1/2	15/32	3/8
5	3	4	1 1/4	2 1/2	3/4	1 1/2	5/8	1/2
5	4	4	1 1/4	2 1/2	1	2	5/8	1/2
5	5	4	1 1/4	2 1/2	1 1/4	2 1/2	5/8	1/2
6	1	3	1 1/4	3/4			15/32	3/8
6	1 1/2	2	1 1/4	3 1/2			5/8	1/2
6	2	2	1 1/4	3 1/2			5/8	1/2
6	2 1/2	4	1 1/4	3 1/2	1/2	1 1/2	15/32	3/8
6	3	4	1 1/4	3 1/2	3/4	1 1/2	5/8	1/2
6	4	4	1 1/4	3 1/2	1	2	5/8	1/2
6	5	4	1 1/4	3 1/2	1 1/4	2 1/2	5/8	1/2
6	6	*7	1 1/4	1 3/4	1 1/4	1 3/4	5/8	1/2
8	1	3	1 1/4	3/4			15/32	3/8
8	1 1/2	3	1 1/4	3/4			5/8	1/2
8	2	5	1 1/4	2 3/4			5/8	1/2
8	2 1/2	5	1 1/4	2 3/4			5/8	1/2
8	3	5	1 1/4	2 3/4			5/8	1/2
8	4	6	1 1/4	2 3/4	1	2	5/8	1/2
8	5	6	1 1/4	2 3/4	1 1/4	2 1/2	5/8	1/2
8	6	6	1 1/4	2 3/4	1 1/2	3	5/8	1/2
8	8	7	1 1/4	2 3/4	1 1/4	2 3/4	5/8	1/2
10	1	3	1 1/2	3/4			15/32	3/8
10	1 1/2	3	1 1/2	3/4			5/8	1/2
10	2	5	1 1/2	3 1/2			5/8	1/2
10	2 1/2	5	1 1/2	3 1/2			5/8	1/2
10	3	5	1 1/2	3 1/2			5/8	1/2
10	4	6	1 1/2	3 1/2	1	2	5/8	1/2
10	5	6	1 1/2	3 1/2	1 1/4	2 1/2	5/8	1/2
10	6	6	1 1/2	3 1/2	1 1/2	3	5/8	1/2
10	8	7	1 1/2	3 1/2	1 1/4	2 3/4	5/8	1/2
10	10	7	1 1/2	3 1/2	1 1/2	3 1/2	5/8	1/2

Fig. 1. Standard Arrangements for the Bolting of Bus and Connection Bars of Copper ¼ in. Thick

more perfect joint will admit a smaller quantity of oxidizing air than the original joint and thus give a better permanency to the joint.

This phenomenon has been a problem for a long time among station operating men. Many of them have observed that joints in laminated conductors cannot be maintained tight and cool unless the bolts are gone over and pulled up tight at least twice after the station has been put in full operation. It has been observed that the bolts can be taken up an appreciable amount each time, regardless of how tight they were bolted up originally. This holds good up to a time when the mushrooming process, just described, has been completed.

From this will be appreciated the importance of applying a good pressure on bolted and clamped joints. Nevertheless, it is important that this be not carried too far. The bolts must not be subjected to stresses beyond their elastic limits, nor must they be too heavy to possess a certain amount of elasticity for taking up the slack of contraction in the joint at drops in temperature.

Design

Considering all these factors, the usual thickness and hardness of the copper bars, and the size and stiffness of the washers generally available, the standard design of bolting shown in Fig. 1 was introduced. It was borne in mind that an incorrect application of bolting pressure would tend to open the contact surfaces along the edges and start oxidation of the contact. In this tabulated design, medium or large size washers were considered, and such are usually available.

Table I was developed as an analysis of the commonly-used bolt sizes and contact pressures obtainable when using standard wrenches and ordinary muscular effort.

TABLE I

PROPERTIES OF STEEL BOLTS AND THEIR APPLICATION IN ELECTRICAL JOINTS

Size of Bolt	A Square Inches	S_l Lb. per Bolt	S_a Lb. per Bolt	T Lb. per Bolt	L Inches	P Lb.
⅜-in.	0.0676	2360	693	1667	5.0	27
½-in.	0.1256	4380	1260	3120	6.5	52
⅝-in.	0.2014	7030	2000	5030	8.5	81

A —Root area of bolt in square inches.
S_l —Elastic limit of bolt in pounds.
S_a—Additional stress in bolt due to expansion of copper.
T —Permissible maximum stress in pounds per bolt.
L —Effective leverage of standard wrench.
P —Force exerted on the wrench to obtain T.

The coefficient of linear expansion of copper is 0.0000168 per deg. C., while that of the steel bolt is only about 0.000011. In addition to this difference which effects a tighter joint during times of electrical heating of the conductor, there must also be considered the result of a time lag in the heating of the bolt behind that of the conductor at the times of increases in the current carried by the conductor. The temperature difference in this time lag may be 10 deg. C. or more for a short time, owing to air insulation around the bolt in the hole, and this greater difference in temperature during the time lag adds a further strain on the bolts. This is the case when the bolts pass through the conductor and not on the outside of it, as in clamped joints. Should the bolt be tightened so much that it is stressed almost to the elastic limit at ambient temperature, the heating caused by electric load would increase the stress sufficiently to elongate the bolt permanently. This action would result in a loose joint which would deteriorate rapidly under the accumulative effect of progressive oxidizing, heating, further oxidizing, further heating, etc.

Considering 35,000 lb. per sq. in. as the elastic limit of steel bolts, with a modulus of elasticity of 29,000,000 it is found from Table I that certain values in pressure must not be exceeded if a permanent joint is to be expected. These values have been translated for the sake of convenience into pounds applied at the end of a standard wrench.

A man of average strength may exert the following force:

Moderate pull	35 lb.
Strong pull	80 lb.
Extreme pull	150 lb.

Thus it will be seen by referring to Table I that the ½-in. bolt is the most suitable for general conditions.

A similar standardization of the bolting dimensions on cable terminals has given a further opportunity for simplicity in design. By adhering to certain common dimensions for the cable terminals and the bar connections, and even further to certain apparatus, *e.g.*, current transformers, an extraordinary simplicity has been obtained in the choice among different sizes of cable terminals and bar connections. As an example of this: Different sizes of bars or different sizes of cables may be connected to a current transformer without interposing splicing plates or adapters. This feature is a factor in space economy as well as in elimination of extra contacts; it also carries with it the convenience of a certain amount of interchangeability in apparatus as the load in a circuit may gradually grow.

In Fig. 3 is shown a standardized bolting for cable terminals of different sizes.

Preservation of Contacts

This is largely a matter of protecting the contact surfaces against the oxidizing influence of air or other corroding agents. Copper being one of the more sensitive metals to oxidation under atmospheric conditions, and because of the comparative ease with which a high-resistance film builds up on its surface even in ordinary air, it has been repeatedly suggested to plate the contact surfaces with some metal that has the property of resisting the corrosion better than copper. Unfortunately, silver is about the only metal whose oxide is a

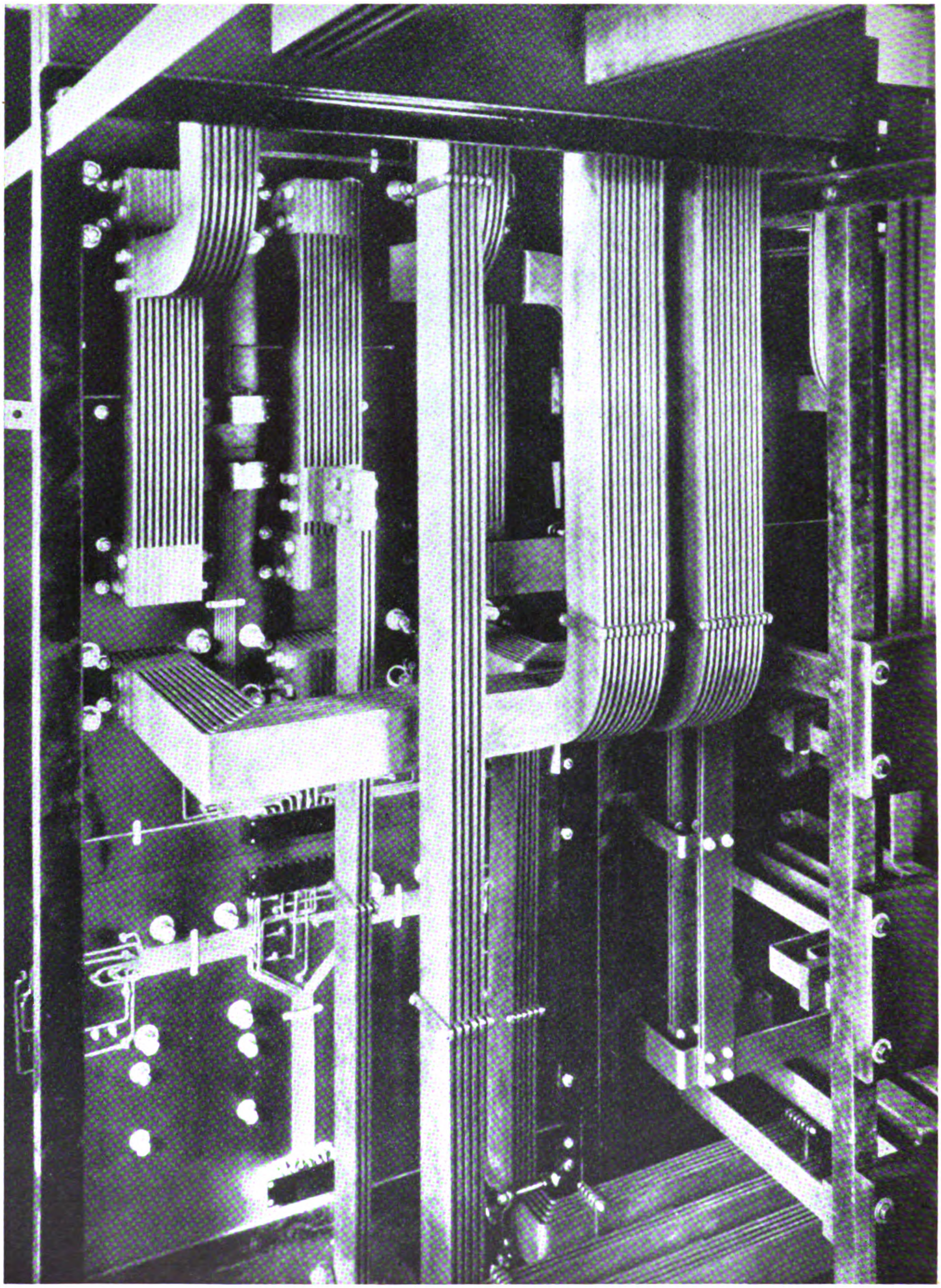

Fig. 2. Typical Installation of Heavy Copper Connections Back of a Switchboard. Note the edgewise bends to reduce the number of joints

conductor so that it can be used for contact surfaces, disregarding its corroding tendency. These measures, however, are seldom practical from an economic standpoint. As a practical remedy, vaseline or oil paint has been used with a great deal of success under ordinary conditions. This method has been almost entirely successful where the conditions of bolting or clamping have been given proper consideration.

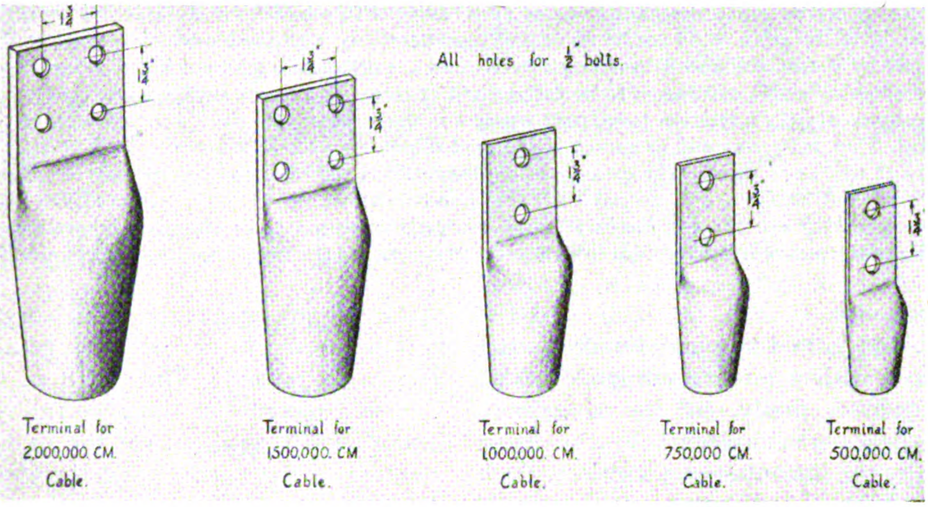
1¾
1¾"
1¾"
1¾"
All holes for ½" bolts.
1¾"
1¾"
1¾"
1¾
Terminal for 2,000,000 CM. Cable.
Terminal for 1500,000. CM Cable.
Terminal for 1,000,000. CM. Cable.
Terminal for 750,000 CM. Cable.
Terminal for 500,000. CM. Cable.

Fig. 3. **General Bolting Dimensions of Cable Terminals, which Coincide Extensively with the Bolting of Bars**

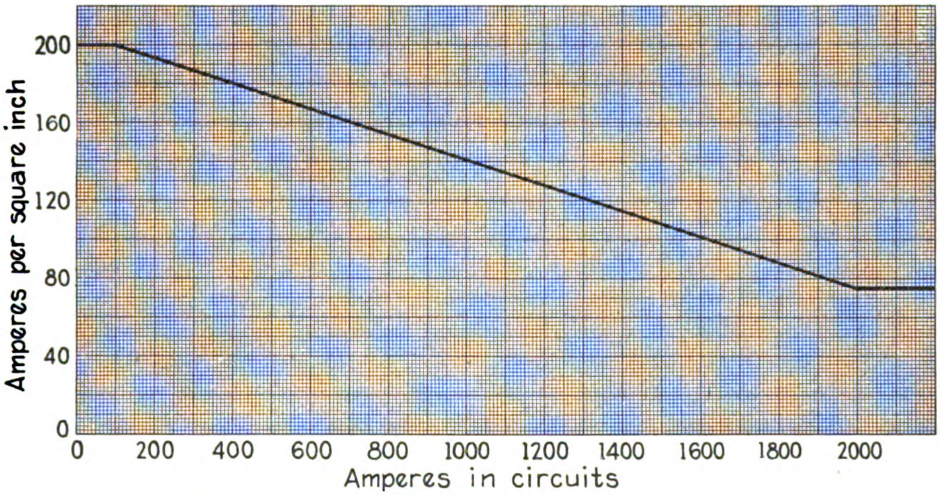

Fig. 4. **Graphic Representation of Ordinary Minimum Limits in Contact Surface of Copper Bars for Different Current Values**

There are, however, cases where extreme changes in temperature increase the problem, first by tending to periodically open the joints; and second by frying out the protective medium. If these conditions should happen to be present together with a corroding atmosphere, as in certain chemical plants, the problem would be very much worse. For such conditions it is necessary to use great care, not only in the selection of this protective material but also in the design of the joints so that the expansion in the conducting material and the bolting or clamping members is well balanced. Besides this, in many cases it may be necessary to further seal the joints by an external application of some elastic material with great adhesive quality, and the further quality of retaining its elasticity with age. There are available in the market today several bituminous substances that meet these requirements to a great extent.

The provision of increasing the contact surfaces beyond a normal limit has often been suggested, and applied with a great deal of success, in order to prevent oxidizing with the corresponding heating of the joints. This method, illustrated in Fig. 4, has been successful on the basis of providing a longer and more difficult path for the oxidizing air to reach the whole contact surface of the joint. Increasing the contact surfaces over a certain limit means an increased cost, and here again it is a matter of balancing one economic factor against another, and to choose that which is found to be most advantageous. As a rule it is not necessary to increase the size of the contact surfaces over the ordinary values except in some special cases where severe corroding action must be carefully guarded against.

Modern Physics—A Survey

PART II

By DR. SAUL DUSHMAN
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Review of Part I: Various phenomena observed in the interaction of matter and energy led to the quantum theory of the nature of energy. Bohr combined this hypothesis with the observed laws of spectral lines to formulate a theory of atomic structure in which Newtonian mechanics was retained along with quantum postulates. However, it was found that this mechanistic model of the atom could not be reconciled quantitatively with the known observations. The new quantum mechanics developed by Heisenberg and Schroedinger overcomes the difficulties inherent in the older theory by postulating that the behavior of microscopic systems is to be interpreted in terms of a wave motion associated with the corpuscular motion, and given by de Broglie's relation $\lambda = h/(mv)$ where λ is the wavelength, mv the momentum of the particle, and h is Planck's constant. Thus matter as well as energy is assumed to possess a dual nature; *i.e.*, both entities possess the properties of corpuscles as well as of waves. The experimental observations that electron beams may be diffracted, like x-rays, by the atoms in a crystal lattice are in accord with this point of view.

In the following installment there is discussed Schroedinger's extension of de Broglie's suggestion, and the physical significance of the conceptions which were thus introduced and constitute the new "quantum mechanics."—EDITOR.

Principle of Indeterminism

How are we to understand this undulatory motion which is associated with a moving corpuscle? Such a corpuscle is defined, firstly, by its momentum (which we shall henceforth designate by the letter p), and secondly by the instantaneous position, which may be designated by one or more coördinates of position, q. Also corresponding to the values of the p and q, the corpuscle possesses a certain total energy which is in general partly kinetic and partly potential. The energy is transmitted with the same velocity as the corpuscle, consequently it must be regarded as located at any instant at the same point in space as the corpuscle.

Now in a monochromatic plane wave, extending to infinity in both directions, it is not possible to choose any given point as that at which the energy is located at a given instant, for all points in the infinitely long train have equal claim to be chosen. But in a group of waves formed by the superposition of a large number of different frequencies, the energy is transmitted at the same velocity as that of the crest or that portion of the resultant wave formed by the addition of the amplitudes of the individual waves. That is, *the energy is transmitted with the same velocity as that of the group*. Hence we must represent the corpuscle in motion as located within the region occupied by this crest and the latter as travelling with the same velocity v as that of the corpuscle.

The fact that the velocity of the individual waves, or phase-velocity, is given by c^2/v, which is greater than the velocity of light, need not worry us, since no energy is actually transmitted with this velocity. This conclusion is therefore not in contradiction with the theory of relativity.

It is evident that in the superposition of waves of different wavelengths the region over which these waves may be caused to add their amplitudes and thus form a crest, of distinctly greater amplitude, is *narrower the greater the range of wavelengths*. Consequently, if we wish to define the *position* of the particle at any instant with a high degree of exactness, it is necessary to choose as large a range of wavelengths as possible. The width of the crest will in fact be a measure of the uncertainty in locating the instantaneous position. On the other hand, the momentum of the particle and therefore its velocity is determined by the wavelength of the associated wave motion, and since it has been found necessary to assume a large range of wavelengths in order to define the position more accurately, it follows that the velocity cannot be defined with the same degree of exactness. Thus, *on the basis of the wave conception of corpuscular motion, there exists a fundamental limitation upon the degree of certainty with which both position and velocity can be determined simultaneously.*

These considerations led Heisenberg to formulate a generalization which defines the exact nature of the limitation. For ordinary cases of macroscopic particles, the degree of uncertainty is so small that it is much beyond the limits of measurement, but for microscopic systems, such as atoms and electrons, the existence of the limitation becomes of fundamental importance. As stated by J. H. Van Vleck(7), Heisenberg's Principle of Uncertainty or Indeterminism postulates that, "When dealing with amounts of action (momentum × distance) comparable with Planck's constant, h, one cannot assign accurate numerical values simultaneously to a coördinate and its corresponding momentum."

The interesting point is that the quantum constant, h, which determines the magnitude of the ultimate units of energy also appears here in an apparently new rôle. However, a consideration of the dimensions of h leads to a further interpretation of the Uncertainty Principle. From the relation $h = E/\nu$, it is seen that h has the dimensions of energy × time, *i.e.*, $mv^2 \times t$. Since this is identical with $mv \times vt = p \times q$ where p denotes a momentum and q a distance along the coördinate, it is readily shown that the Uncertainty

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(7) New Quantum Mechanics, *Chem. Rev.* *5*, 467 (1928).

Principle can also be stated more precisely in the following form:

If Δp denote the inaccuracy in specifying a momentum, and Δq that in specifying the corresponding coördinate, then the product $\Delta p \cdot \Delta q$ of the two errors is always of the same order of magnitude as the constant h, that is

$$\Delta p \cdot \Delta q \sim h.$$

The significance of this relation for atomic phenomena is best presented in the following quotation which is, again, taken from Van Vleck's paper:

"This," he states, in reference to the above relation, "is the so-called *Heisenberg indeterminism principle*, and, like the second law of thermodynamics, is very useful in predicting what experiments are possible, and what are inherently impossible. Thus high precision in position implies low precision in velocity, and *vice versa*, for the error Δv is of the order $h/(m\Delta x)$, and therefore increases as we decrease Δx. We may illustrate this in a crude arithmetical way by considering the motion of an electron. If we specify that this electron is exactly at a given position, say the origin, at a given instant $t=0$, then the error Δx is zero, and consequently the error Δv is infinite; this means that the velocity is inherently undetermined and so can range anywhere from $-\infty$ to $+\infty$; so that at any subsequent instant of time, say one second, there is an overwhelming chance that the electron be an infinite distance away. Suppose, however, that instead of aiming to specify accurately the position of the electron at $t=0$, we merely say that then it is somewhere between $x=-\frac{1}{2}$ and $x=+\frac{1}{2}$; then $\Delta x=1$, and Δv is of the order $\frac{h}{m}$; now $h=6.55\times10^{-27}$, while for an electron $m=0.9\times10^{-27}$, hence the error Δv in velocity is $6.55/0.9$, or about 7 centimeters a second. One could then not give accurately a numerical velocity, say 300 cm. per sec., but one could say that the velocity lay somewhere between about 296½ and 303½ cm. per sec., so that after one second the electron would be between about $x=296$ and $x=304$. (This is only a very crude calculation; a more accurate study leads to a Gaussian error curve.)

"Another, and better illustration of the Heisenberg indeterminism principle is furnished by an attempt to measure simultaneously both the position and frequency of a packet or wave train of light energy. A prism will record a train of waves as being strictly monochromatic only if the train is infinitely long; the termination of the optical disturbance after a finite time interval will cause an interruption in periodicity and make the light in the prism appear diffuse. If the train contains n waves, it can be shown that the diffuseness in its spectrum will be of the order $1/n$, or in other words the fractional error $\Delta\nu/\nu$ in determining the frequency is comparable with $1/n$. If, following the light quant theory, we assign a packet or "quant" of light a momentum $p=h\nu/c$, then Δp is of the order $h\nu/cn$. On the other hand the length of the wave train is $n\lambda$, where λ is the wavelength, and consequently the position of the light is indefinite to an extent $\Delta x=n\lambda$. As $\nu=c/\lambda$, the product $\Delta x\Delta p$ of the two errors is of the order of Planck's h.

"Because of the ambiguity resulting from the Heisenberg indeterminism principle, the future of a dynamical system can never be predicted with certainty. Instead only the *probability* that an electron be in a given configuration can be determined, and the future is only statistically determined. This is in sharp contrast to the 'causality principle' of classical dynamics, whereby the subsequent history of a dynamical system is determined if we know its initial coördinates and velocities. The uncertainty as to subsequent motion in quantum mechanics is, however, perhaps not due so much to failure of the ordinary cause and effect relation as to the inevitably indeterminate character of the initial conditions, as by the Heisenberg indeterminism principle one cannot give both . . . *Thus quantum mechanics is essentially a means of calculating the probabilities of events.* In a laboratory experiment one performs certain operations and observes certain consequences. The goal of a theory must ever be to explain 'what goes out' in terms of 'what is put in.' At first thought it may appear as if the purely statistical correlation between cause and effect demanded by quantum mechanics is contradictory to the precision with which experiments can be performed. Experiments with large scale quantities, however, involve so many quanta that the Heisenberg indeterminism is obscured, and so there is only apparently a 'sharp' correlation. On the other hand, our ordinary atomic or molecular experiments are in most cases fundamentally statistical in character, as what is measured is not particular values of the dynamical variables, but rather *average values* of certain functions of these variables, or else *distributions* telling how they are scattered over a wide range of values. Such statistical quantities have a meaning in, and can be calculated with, quantum mechanics, and so there is no contradiction of Heisenberg's principle."

To be specific, let us consider the classical concept of an electronic orbit. We have extrapolated this idea from our experience with Newtonian mechanics in calculating planetary motions. In the latter problem we obtain splendid agreement between observations and calculations because the positions of the planets in our gross scale of time and space are unaffected by the act of observing. But is it possible to observe an orbit of an electron? The answer must be in the negative, because whatever experiment we devise to make such an observation will spoil the system. For it would be necessary to illuminate the particle, and to obtain a more precise determination of the instantaneous position we would use gamma rays. But in consequence of the Compton effect the electron would suffer a recoil in a direction which is determined by the change in frequency of the recoiling photon. *Thus by the very act of observation all possibility has been removed of determining accurately the position of the electron at the instant of observation.*

As Bohr has remarked in a notable address on the same subject:(8) "Our usual description of physical phenomena is based entirely on the idea that the phenomena concerned may be observed, without disturbing them appreciably. . . . Now the quantum postulate implies that any observation of atomic phenomena will involve an interaction with the agency of observation not to be neglected. . . . Just as the relativity theory has taught us that the convenience of distinguishing sharply between space and time rests solely on the smallness of the velocities ordinarily met with compared to the velocity of light, we learn from the quantum theory that the appropriateness of our usual casual space-time description depends entirely upon the small value of the quantum of action as compared to the actions involved in ordinary sense perceptions."

The principle of indetermination stated for a coördinate and momentum in a previous equation may also be applied to the simultaneous determination of energy and time in the form

$$\Delta t \,.\, \Delta E = \Delta x.\ \ \Delta p \sim h$$

Thus, given an absolutely monochromatic wave (for which therefore $\Delta E = 0$), then as pointed out in the quotation from Van Vleck, the wave train must be infinitely long, and therefore the uncertainty in t is infinitely great. The representation in wave mechanics of a particle, moving with momentum mv, by a wave packet necessarily leads to an uncertainty in the position of the particle if mv is known very accurately. "For the use of wave-groups," as Bohr states, "is necessarily accompanied by a lack of sharpness in the definition of period and wave-length, and hence also is the definition of the corresponding energy (E) and momentum (P) as given by the relation

$$E/\nu = P\lambda = h.$$

"Rigorously speaking, a limited wave-field can be obtained only by a superposition of a manifold of elementary waves corresponding to all values of ν. But the order of magnitude of the mean difference between these values for two elementary waves in the group is given in the most favorable case by the condition

$$\Delta t \Delta \nu = \Delta x \cdot \Delta \sigma = 1."$$

From this relation Heisenberg's principle follows directly on multiplying both sides by the constant h.

From this discussion it perhaps becomes evident why it is that the matrix calculus with its irrational variables and the wave mechanics with its imaginary wave-packets to represent actual particles both lead to the same conclusions. It is the existence of the principle of indeterminism that really ties them together philosophically.

Schroedinger's Wave Equation

All this leads to the logical conclusion that the laws of ordinary mechanics cannot be applicable in the usual manner to problems in atomic mechanics. We have to devise some modification in the Newtonian method which shall take into account the undulatory aspects of corpuscles when these are of atomic or electronic dimensions. Furthermore, it is an obvious deduction from the principle of indeterminism that all attempts to obtain from the solution of problems in atomic mechanics a definite answer regarding the occurrence of any individual event are foredoomed to failure. In view of the uncertainty in the definition of initial conditions we cannot expect a precise definition of subsequent occurrences. There must exist a measure of uncertainty in the prediction of events and hence *all that we can determine from the solution of a problem in atom mechanics is the probability of any individual event.*

The Schroedinger wave mechanics performs exactly these two functions. Firstly, it represents an undulatory conception grafted on the ordinary mechanical formulation of any problem in atom mechanics and secondly, once the solution is obtained (which is accomplished by well-known methods in the theory of differential equations) *the answer is interpreted in terms of probabilities.*

The first stage in the solution of a problem by Schroedinger's method may therefore be described as that in which we formulate the problem in the same manner as in ordinary or classical mechanics. That is, we assume an actual model of, say, the orbit of an electron in a hydrogen atom, or the motion of a linear harmonic oscillator. In classical mechanics the most general method for expressing the motion of a system is that which states the total energy (E) of the system under consideration as a function of the coördinates and the corresponding momenta. That is, the energy is expressed in terms of the kinetic and potential energies as functions of the instantaneous coördinates. Formulated in this manner the expression for E is said to be of the Hamiltonian form.

Ordinarily we would proceed to solve this problem by certain standard methods and the result would enable us to describe the motions of the different parts of the system in terms of certain orbits or paths. Thus in the well-known Newtonian problem of the planetary motions, the starting point is the postulate that the planet and sun exert an attractive force on each other which varies inversely as the square of the distance. This gives us the potential energy of the system as a function of the distance. Furthermore, we can express the kinetic energy of the planet in terms of its mass and instantaneous velocity. We can therefore write down an expression for the total energy. The problem now consists in the determination of the exact path followed by the earth in its motion under the attractive force. The "answer" deduced is that the orbit must be an ellipse with a major axis and frequency of revolution defined by the total energy of the system.

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(8) *Nature* *121*, 850 (1928).

However, in Schroedinger's method the *use of classical conceptions ceases after we have once formulated the total energy in a Hamiltonian form.* We forget all about the model of a corpuscle moving with definite velocity in a well defined orbit. Instead of proceeding as in classical dynamics, we now bring in the wave concept and use the Hamiltonian expression to calculate the "wavelength" of the associated undulatory motion. Thus if E represents the total energy, and V the potential energy, then $E-V$ denotes the kinetic energy at any instant and from the relation

$$(1/2)mv^2 = E - V$$

it follows that the momentum

$$mv = \sqrt{2m(E-V)}$$

and since the wavelength of the de Broglie wave is given by $\lambda = h/(mv)$, we obtain for λ in the dynamical problem the result

$$\lambda = \frac{h}{\sqrt{2m\,(E-V)}}$$

We now replace the motion of the particle by that of a wave front travelling in a medium in which the velocity varies continuously from point to point; for the velocity depends upon the potential energy, V, and the latter is a function of the coördinates only. Consequently the wave front of the associated wave motion is continually suffering "refraction" in the field of force and the direction of the normal to the wave-front will be the same at every point as the tangent at that point to the orbit of the particle in the classical case.

Thus the problem becomes one of determining both the direction and amplitude at any point and instant of time of an undulatory motion for which the wavelength as a function of the coördinates is given by the foregoing relation. In other words, the problem has now become one of *undulatory* mechanics, and can be formulated in terms of a differential equation which expresses the second derivative of the amplitude with respect to time in terms of the instantaneous phase-velocity and of the second derivatives of the amplitude with respect to the coördinates. The partial differential equation of the second order which is thus obtained is Schroedinger's famous equation.

Solutions of this equation are then sought which will give the amplitude as a finite and continuous function of the coördinates at any instant of time. The amplitude as a function of both coördinates and time is designated by ψ. The form of the equation is in general such that it is possible to express this function as a product of a function ϕ, of the coördinates only, and a cosine or sine series involving the time. Since we are also usually more interested in the equation for the "orbit," we need consider only the form of the function ϕ. Therefore we can, in general, summarize the whole of the above process by stating that from the Hamiltonian expression for E it is possible by making use of de Broglie's equation for the wave equation to derive a certain differential equation (the Schroedinger equation) which gives the relation between the second order partial differential coefficients of a function ϕ with respect to the coördinates and the quantities E and V.

Whatever the physical significance of ϕ (or ψ) may be (this we shall discuss in a subsequent section), it is obvious that only those solutions of the differential equation can have any meaning whatever which are finite and continuous for all possible values of the coördinates. Now it is the peculiarity of Schroedinger's form of wave equation that the solutions fulfill these requirements only for certain discrete values of E, which are known as *eigenwerte* or *characteristic values,* and it is found that for the different problems in atomic mechanics *these eigenwerte are identical with the values of the energy levels as calculated by the classical Bohr theory* (whenever this is possible) or as determined from spectral observations. The corresponding solutions for ϕ are known as *eigenfunctions* or *characteristic functions.* The whole problem of solving Schroedinger's equation is, as a matter of fact, analogous to the more familiar problems in acoustics, of determining the positions of the nodes and the amplitudes of the loops in a vibrating string or organ pipe. The functions ϕ thus resemble standing waves with *the number of nodes equal to the classical quantum number of the Bohr orbit.* These functions have appreciable values only in those regions which would be occupied according to the older theory by the electronic orbits, and for distances greater than the radii of these "orbits" the values of ϕ decrease very rapidly to zero. In other words, the amplitude of the wave motion has values greater than zero only in the neighborhood of the classical orbit.

On the whole, the calculation with Schroedinger's eigenfunctions is more convenient than that involving matrices. While it was at first thought that the Schroedinger method and that of the matrix calculus are radically different, it was shown by Eckart, Dirac, and Jordan that both methods are essentially identical from a mathematical point of view and are, in fact, both reducible to a much more general kind of mathematics, the calculus of operators.

Significance of Schroedinger's Eigenfunction

So far we have spoken of an amplitude of a wave-motion, designated by ϕ (or ψ) and have said nothing about a "medium." It will be remembered that when the electromagnetic wave theory was first postulated it appeared necessary also to postulate a medium, the ether, in which electromagnetic waves are transmitted. As is well known, all attempts to demonstrate the existence of such a medium, as, for instance, the famous Michelson-Morley experiment, have yielded negative results, and the reason for this was provided by the theory of relativity. Furthermore, regarding the very nature of electro-magnetic energy we have found it necessary to postulate a dualistic conception. On the one hand, in interference and diffraction we think of a wave motion and measure wavelength (λ) and frequency (ν). On the other hand, in phenomena involving interaction between energy and atoms or electrons (as in the photo-electric and Compton effects) energy behaves as a corpuscular entity involving those attributes which are characteristic of corpuscle, that is, energy of magnitude, $h\nu$, and momentum of magnitude, $h\nu/c = h/\lambda$.

This association of wave and particle concepts is also seen to hold for electrons in Davisson and Germer's experiments, for when the mechanical momentum is varied, the wave-number (reciprocal of λ) or wavelength effective for diffraction of the electron beam varies in just the manner given by the equation $p = h/\lambda$.

Now in the case of radiation, Einstein had already suggested that the electromagnetic field in a given region determines the *relative probability* that the quanta go to different places. "In a set of interference fringes, the wave amplitude is strong at some places, and weak at others. The quanta go to the different places with a *relative probability* that is given by the wave measure of intensity, *viz.*, the *square of the wave amplitude.*" (9)

Following this suggestion, M. Born has put forward a similar interpretation of ϕ^2 (or ψ^2). The square of Schroedinger's function for the "amplitude" of a wave-motion denotes the relative probability of occurrence of a certain event at a given point in space and at a given instant of time. Thus in the case of the hydrogen atom, we obtain a solution which gives the eigenfunctions for the different states of the atom, corresponding to the different possible orbits of the electron in the Bohr theory. These functions express the amplitude (ϕ) as a function of the distance (r) from the nucleus and of two angles which denote the longitude and colatitude respectively.

Schroedinger originally interpreted ϕ^2 as proportional to the relative charge density of negative electricity at a given point. Since, as mentioned already, ϕ has finite values from $r = 0$ to a value of r which is slightly greater than the radius of the corresponding Bohr orbit, this interpretation leads to a representation of the electron in the hydrogen atom as "smeared out" in a spherical space having approximately the same dimensions as the atom.

On the basis, however, of Born's conception, the value of ϕ^2 corresponding to any given point in space merely denotes the probability of finding the electron at that point. *Thus the conception of a definite orbit is replaced by that of a certain region in the space surrounding the nucleus for which the probability of occurrence of the electron is greater than that for any other region.*

This interpretation of ϕ has the advantage that it eliminates completely all speculation regarding the physical reality of a wave motion associated with a corpuscle in motion. For ϕ may be a function of more than three coördinates, as, for instance, in the case of the helium atom where we are dealing with the motions of two electrons and, therefore, require six coördinates. Under these conditions ϕ^2 denotes the probability of the simultaneous occurrence of the two electrons in two specified positions, and since the probability of such an event is equal to the product of the individual probabilities there follows another important advantage of Schroedinger's method, *viz.*, it permits us, theoretically, at least, (*i.e*,, apart from difficulties in the mathematical technique) to solve the problem of an atom containing two, or even more, electrons.

In this manner the difficulty of the three-body problem in classical dynamics does not occur in the new mechanics. For in the latter we consider ϕ as determined by the total field of force which is due to the interaction of all the electrons and the nucleus, whereas in the ordinary mechanics we must take into account phase relations among the electrons.

As has been mentioned already, this interpretation of ϕ^2 as a probability follows logically from Heisenberg's principle of indeterminism, and, indeed, supplements it by making the whole idea more precise mathematically. We thus perceive that it is the interplay of wave and corpuscular concepts which leads to the view of the new quantum theory as essentially a statistical theory. The problem of what occurs in any individual instance is left unanswered. All that the Schroedinger equation can yield is information about the probability for the occurrence of a certain event.

In statistical mechanics this point of view has been applied since the time of Boltzmann in order to solve many problems such as those in the kinetic theory of gases, in the scattering of alpha particles by thin foils, and similar phenomena. In this mode of treatment micro-coördinates were introduced and then eliminated by taking statistical averages of the results. In wave mechanics, however, we avoid this procedure, since we derive the statistical probabilities directly from the solution of the Schroedinger equation. As Born (10) describes the logic involved, "We regard the particles as acted upon by Coulomb forces, but the forces are not, as in classical physics proportional to the acceleration. In fact they have no direct relation with the motion of the particles. Rather, the wave-field comes in between. The forces determine the variation of a certain magnitude, ϕ, *which depends upon the positions of all the particles simultaneously* (it is therefore a function in the 'configuration space') *and in this manner that ϕ must satisfy a differential equation of which the coefficients depend upon the forces.*

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(9) E. U. Condon: *Science 68*, 193 (1928). The writer is responsible for the italicized portions.

(10) *Naturwiss 15*, 238 (1927).

"The knowledge of the function ϕ permits us to calculate the course of a physical phenomenon, as far as it is determined by quantum mechanical laws, that is, *not in the sense of causal determinism but in the sense of probability.*"

In classical dynamics the problem is always stated thus: Given the initial conditions in all their details, also the forces acting on the particles and the total energy, what is the condition at any given subsequent instant of time? On the other hand, we find that in the case of problems in atomic physics it is impossible to formulate the problem in this manner. Because of the indeterminacy of the initial conditions all we can state is the probability of a given condition at any subsequent instant of time. There exists a certain probability that the system shall be in a given state and also another assignable probability that it shall be in another given state.

It is in this sense that we must abandon the causality principle as applied to atomic physics. This principle can no longer be regarded as valid for individual occurrences, but rather for the *probability function*, ϕ^2. All we can predict is the manner in which this probability must vary with time. It is, therefore, in this sense only that we can still regard the causality principle as applicable to quantum phenomena.

The interpretation of ϕ^2 as a probability and the significance of this from the point of view of the classical principle of causality are still more strikingly emphasized by the method used in the new mechanics for calculating the intensity of spectral lines. On the basis of the Correspondence Principle, Bohr derived the conclusion that transitions between certain types of energy levels cannot occur, and that, therefore, the intensities of the lines corresponding to these transitions must be zero. But according to both the matrix theory and Schroedinger's wave mechanics the intensity of a spectral line is given by the *probability of the coexistence* of the functions ϕ_i and ϕ_f for the initial and final states of the atomic system. That is, the intensity of any line depends upon the magnitude of the product of two functions, one for the initial and the other for the final state. In this deduction it is readily evident how far we have diverged from any classical notions of causality. For, the most treasured feature of this principle is that the end state cannot have any effect on the phenomena which lead up to it. How, then, are we to interpret the wave-mechanics calculation of intensities of spectral lines? Perhaps the best way is to accept the result because it leads to the correct answer, and forget the causality principle, at least in atomic problems.

This means that our criterion for applying the principle of causality fails in the case of atomic systems. Can we ever be sure that two atoms are in the same initial state? The answer is necessarily in the negative, for in attempting to observe the state of the atom we must bombard it with atoms, photons or electrons, and in each case the act of observing changes the state in an indeterminate manner. Hence, according to Bohr and Heisenberg, we must conclude that in the atom space and time are in some manner complementary, and therefore we can no longer apply to such cases the conceptions which we have found so useful for ordinary or large-scale phenomena.

Some Applications of Quantum Mechanics

It would take us much beyond the scope of the present article to treat of the applications of the new mechanics to various problems of atomic and molecular structure, to line and band spectra, and still more recently to problems of chemical valency. By means of the new quantum theory, it has been found possible not only to derive all the results obtained by the older Bohr theory, but also to account for observations which could not be made to fit in with the latter. Furthermore, the theory represents, in many ways, a more logical approach towards the ultimate goal of any branch of science—a quantitative correlation of observable magnitudes.

It is, however, of special interest to mention briefly one consequence of the wave mechanics conception which is of greatest importance and yet represents a totally unexpected departure from the usual point of view.

In ordinary mechanics, we accept as a necessary consequence the statement that it is impossible for a particle ever to occur at a point in space for which the potential energy (V) would exceed the total energy (E). For instance, in the case of a vibrating pendulum the maximum amplitude of oscillation is determined by the condition that at this point the potential energy is just equal to the total energy. But in quantum mechanics, the path of the particle is no longer confined to just that region in which V is less than or equal to E. The function ϕ, which defines the amplitude, and ϕ^2, which determines the probability of occurrence of the particle at any point, are found to have *finite* values for regions which extend beyond those in which the motion of the particle would be confined according to classical mechanics. In other words, there exists a certain measurable probability (which is usually very small) that the particle will be found in those regions which, according to ordinary mechanics, are forbidden. The reason for this surprising result is evidently to be found in the uncertainty principle, for in atomic mechanics there is no longer any precise correlation between simultaneous values of position and momentum such as is demanded by Newton's laws.

Now let us consider the case of two regions of low potential energy (designated as regions I and II) separated by a central one of relatively high potential energy (region III). According to ordinary mechanics if the particle is moving in *either* region I or II, then it must *certainly remain there for all time*, unless it is supplied with additional energy from an external source sufficient to bring it over the "hill" which comprises region III. But on the basis of the fact that ϕ^2 varies continuously from one region of low potential energy, through region III, into the other region of low potential energy, it follows that we can no longer regard a transition from region I to II, or *vice versa*, as impossible. Rather, for the certainty of classical mechanics regarding the impossibility of such an occurrence we must substitute, according to the new point of view, the existence of a finite *probability that in the course of time such a transition may occur.* (11)

It is by applying this consequence of the new theory that it has been found possible, for the first time, to obtain an interpretation of such aperiodic phenomena as the disintegration of radioactive elements, electron emission from cold metals under the action of strong fields, and the photoelectric effect.

Concluding Remarks

To a large number it has seemed that the new point of view necessarily leads to an abandonment of Bohr's model of the atom as constituted of a nucleus with one or more electrons revolving about this nucleus in elliptic orbits. That, however, this opinion is not quite justified must be evident when we consider that in the very development of Schroedinger's equation in any problem the first step involves the formulation of the energy in terms of a model. It is only the mathematical method of solving the problem which has been modified, but the electronic orbits must still remain. Perhaps they emerge in not quite so concrete a form as the older theory represented them. The simple elliptic orbit is replaced by an annular shape, or some other more complicated spatial figure at all points of which we may regard the electron as located at any instant with a certain measure of probability.

The picture has, as it seems, become more "fuzzy" on the edges; this must be so because of the essential indeterminism in our knowledge of phenomena within the atom itself. But for the interpretation of many of the observations in atomic physics the older view need not necessarily be any less "true" than it ever was. For after all, a scientific theory is a framework wherein we may fit together the broken parts of a picture puzzle, and, oftentimes, if we are content to select a smaller number of parts, the framework may be made to appear a little less complicated.

Yet, granted all this, the fact remains that we must recognize the same dualism in regard to both matter and radiation. Whether we shall ultimately find a monism behind this dualism, only the future can reveal. If this event does occur, *it will be because of additional experimental observations which cannot be adapted to conceptions held valid at present.*

Philosophically, the doctrine of indeterminism and its consequent deduction that atomic phenomena are governed by laws of probability, will appear to many as an extremely unsatisfactory dénouement for a branch of science which hitherto has always prided itself on the preciseness of its deductions. P. W. Bridgman, in his extremely interesting book on "The Logic of Modern Physics," has expressed this feeling in the following remarks:

"In general, we cannot admit for a minute that a statistical method, unless used to smooth out irrelevant details, can ever mark more than a temporary stage in our progress, because the assumption of events taking place according to pure chance constitutes the complete negation of our fundamental assumption of connectivity; such statistical methods always indicate the presence of physical complications which it must be our aim to disentangle eventually."

And from a pure philosopher comes the complaint that physics has now become metaphysics! (12) Perhaps the philosopher may be excused for not understanding Schroedinger's equation.

What does it all mean? Are there structures beyond the electron and the quantum, as Bridgman would suggest? Must we conceive nature to be ultimately simple, just because we have an aesthetic predilection for such a conception? On the contrary, the history of science teaches us that as we search deeper into the mysteries of nature, the more complex does it appear, and hence there is no reason, except that of mental inertia, for expecting nature to remain always simple—by which we mean that we can make mechanical models which will show us how the "wheels go round." It would, of course, be extremely convenient if nature could always have arranged things to suit our standardized modes of thinking at any period. But the history of human progress has been one in which vision and interpretation have grown with actual knowledge, and therefore we must not be shocked too severely if the present ideas of quantum mechanics appear on the one hand as a negation of our fondest expectations of the past, and on the other, as a mass of abstract and almost transcendental mathematical notions. Time will undoubtedly breed familiarity, and, perhaps ultimately, disdain for the "simple" ideas of the present. But that the future will reveal to us still more complex phenomena and that these in turn will necessitate still more radical ideas—these things none dare deny.

(*Concluded*)

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(11) This conception has been very thoroughly discussed by R. W. Gurney and E. V. Condon: *Phys. Rev.* *33*, 127, (1929).

(12) W. Durant: *The Mansions of Philosophy*, p. 64. It is worth while for any scientifically trained person to read the remarks of Dr. Durant, for it is always of interest to see ourselves as others see us, even if we believe them to be mistaken.

The Force Between Unequal Reactance Coils Having Parallel Axes

Formulas for Solution of Problems by Direct Substitution of Physical Values—Useful When Determining Force Between a Small Feeder Reactor and a Nearby Large Bus Reactor—In Determining Effect of Leakage Magnetic Field of Reactor on Surrounding Structural Steel Bodies—In Calculating the Voltage One Reactor Induces in Another

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AIR-CORED reactors, or reactance coils, are frequently mounted with vertical axes. In a group of reactors mounted in a power station there are sometimes more than one size of coil, and so it becomes of practical value to have methods of calculating the force and mutual inductance of unequal solenoids with parallel axes. Formulas for this purpose are presented in this article.

Formulas for the force and mutual inductance of equal solenoids with parallel axes were published in 1919,(1) and the formulas here given are further developments along the same line. A feature obtainable with calculations of unequal coils is that a formula is given for the component of the magnetic field near a solenoid, parallel to its axis.

The basis of this calculation, as in the former case, is the formula given by S. Butterworth(2) for the mutual inductance of two unequal circles each formed of one turn of infinitesimally fine wire, the axes of the circles being parallel, and separated by a distance larger than the sum of their radii. This expression has been integrated four times, so as to take account of the thicknesses of the solenoids as well as their lengths, the following result for unequal circular solenoids with parallel axes (Fig. 1) being obtained:

M (in henrys) =

$$\frac{\pi^2 A^2 a^2 N_1 N_2}{0.3937\, B\, b\, 10^9}\Bigg[\left(\frac{1}{G_1}-\frac{1}{G_2}-\frac{1}{G_3}+\frac{1}{G_4}\right)\left(1+\frac{T^2}{12\,A^2}\right)\left(1+\frac{t^2}{12\,a^2}\right)-\frac{1}{8}\left\{2\left(\frac{1}{G_1^3}-\frac{1}{G_2^3}-\frac{1}{G_3^3}+\frac{1}{G_4^3}\right)\right.$$

$$\left.-3\,s^2\left(\frac{1}{G_1^5}-\frac{1}{G_2^5}-\frac{1}{G_3^5}+\frac{1}{G_4^5}\right)\right\}\left\{A^2\left(1+\frac{T^2}{2A^2}+\frac{T^4}{80A^4}\right)\left(1+\frac{t^2}{12a^2}\right)+a^2\left(1+\frac{T^2}{12A^2}\right)\left(1+\frac{t^2}{2a^2}+\frac{t^4}{80a^4}\right)\right\}$$

$$+\frac{1}{64}\left\{8\left(\frac{1}{G_1^5}-\frac{1}{G_2^5}-\frac{1}{G_3^5}+\frac{1}{G_4^5}\right)-40\,s^2\left(\frac{1}{G_1^7}-\frac{1}{G_2^7}-\frac{1}{G_3^7}+\frac{1}{G_4^7}\right)+35\,s^4\left(\frac{1}{G_1^9}-\frac{1}{G_2^9}-\frac{1}{G_3^9}+\frac{1}{G_4^9}\right)\right\}.$$

$$\left\{A^4\left(1+\frac{5}{4}\,\frac{T^2}{A^2}+\frac{3}{16}\,\frac{T^4}{A^4}+\frac{1}{448}\,\frac{T^6}{A^6}\right)\left(1+\frac{t^2}{12a^2}\right)+3\,A^2 a^2\left(1+\frac{T^2}{2A^2}+\frac{T^4}{80A^4}\right)\left(1+\frac{t^2}{2a^2}+\frac{t^4}{80a^4}\right)\right.$$

$$\left.+a^4\left(1+\frac{T^2}{12A^2}\right)\left(1+\frac{5}{4}\,\frac{t^2}{a^2}+\frac{3}{16}\,\frac{t^4}{a^4}+\frac{1}{448}\,\frac{t^6}{a^6}\right)\right\}\Bigg] \qquad (1)$$

where N_1 and N_2 are the turns in each coil,

$$G_1=\left\{s^2+\left(u+\frac{B+b}{2}\right)^2\right\}^{1/2}$$

$$G_2=\left\{s^2+\left(u-\frac{B-b}{2}\right)^2\right\}^{1/2}$$

$$G_3=\left\{s^2+\left(u+\frac{B-b}{2}\right)^2\right\}^{1/2}$$

and $$G_4=\left\{s^2+\left(u-\frac{B+b}{2}\right)^2\right\}^{1/2}$$

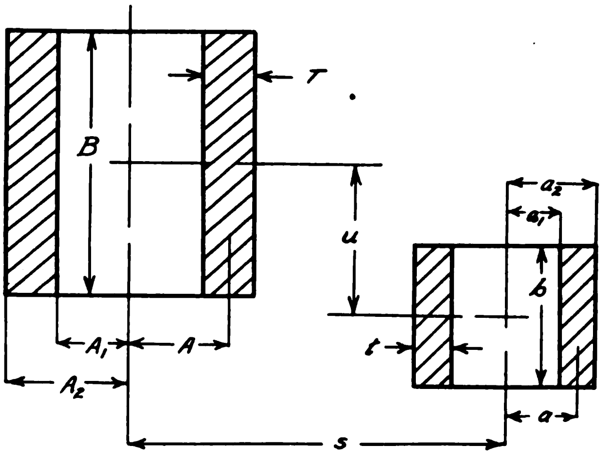

Fig. 1. Dimensional Sketch of Unequal Reactance Coils Having Parallel Axes

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(1)"Some New Formulas for Reactance Coils," by H. B. Dwight, *Trans. A.I.E.E.*, 1919, page 1675.

(2)*Philosophical Magazine*, Vol. 31, 1916, p. 443; and Scientific Paper No. 320 of the Bureau of Standards, Washington, D. C., June, 1918, Eq. 10 A.

The dimensions are assumed to be given in inches; if they are given in centimeters, the factor 0.3937 should be omitted. Each dimension of the coil should be taken equal to the number of wires or cables in that dimension times their pitch, the values of the dimensions thus being slightly greater than the actual lengths measured over the copper.

If the two coils are alike, so that $A=a$, $B=b$, $T=t$ and $N_1=N_2$, this formula becomes the same as Equation (3) in the article to which reference has been made.(1)

Formula (1) includes the case of two coaxial coils, when they are not near together. When the coils are coaxial, the mutual inductance is opposite in sign to the value when the coils are side by side.

Example 1: Two reactance coils with parallel axes, as shown in Fig. 1. Dimensions in inches. $A=3.08$, $B=5.62$, $T=0.55$, $N_1=1142$, $a=4.635$, $b=0.95$, $t=1.635$, $N_2=516$, $s=12.20$, $u=2.90$,

$$M = \frac{\pi^2 \times 3.08^2 \times 4.635^2 \times 1142 \times 516}{0.3937 \times 5.62 \times 0.95 \times 10^9}\Big(0.00220 + 0.00030 + 0.00004\Big)$$

$$= 1.43 \times 10^{-3} \text{ henry (calculated).}$$

The mutual inductance was measured by passing 60-cycle current through one coil and reading the e.m.f. induced in the other. This gave

$$M = 1.47 \times 10^{-3} \text{ henry (measured).}$$

The components of the mechanical force exerted on a coil when currents flow in the coils may be computed by differentiating Formula (1) for M.

The component of force perpendicular to the axes is obtained(3) by taking the partial derivative of Formula (1) with respect to s. It is as follows, in pounds for one ampere in each coil:

$$F_s = \frac{\pi^2 A^2 a^2 N_1 N_2}{4.45 \times 10^7 B b}\Bigg[s\left(\frac{1}{G_1^3} - \frac{1}{G_2^3} - \frac{1}{G_3^3} + \frac{1}{G_4^3}\right)\left(1 + \frac{T^2}{12A^2}\right)\left(1 + \frac{t^2}{12a^2}\right) - \frac{3}{8}\left\{4s\left(\frac{1}{G_1^5} - \frac{1}{G_2^5} - \frac{1}{G_3^5} + \frac{1}{G_4^5}\right)\right.$$
$$\left. - 5s^3\left(\frac{1}{G_1^7} - \frac{1}{G_2^7} - \frac{1}{G_3^7} + \frac{1}{G_4^7}\right)\right\}\left\{A^2\left(1 + \frac{T^2}{2A^2} + \frac{T^4}{80A^4}\right)\left(1 + \frac{t^2}{12a^2}\right) + a^2\left(1 + \frac{T^2}{12A^2}\right)\left(1 + \frac{t^2}{2a^2} + \frac{t^4}{80a^4}\right)\right\}$$
$$+ \frac{15}{64}\left\{8s\left(\frac{1}{G_1^7} - \frac{1}{G_2^7} - \frac{1}{G_3^7} + \frac{1}{G_4^7}\right) - 28s^3\left(\frac{1}{G_1^9} - \frac{1}{G_2^9} - \frac{1}{G_3^9} + \frac{1}{G_4^9}\right)\right.$$
$$\left. + 21s^5\left(\frac{1}{G_1^{11}} - \frac{1}{G_2^{11}} - \frac{1}{G_3^{11}} + \frac{1}{G_4^{11}}\right)\right\}\left\{A^4\left(1 + \frac{5}{4}\frac{T^2}{A^2} + \frac{3}{16}\frac{T^4}{A^4} + \frac{T^6}{448A^6}\right)\left(1 + \frac{t^2}{12a^2}\right)\right.$$
$$\left. + 3A^2a^2\left(1 + \frac{T^2}{2A^2} + \frac{T^4}{80A^4}\right)\left(1 + \frac{t^2}{2a^2} + \frac{t^4}{80a^4}\right) + a^4\left(1 + \frac{T^2}{12A^2}\right)\left(1 + \frac{5}{4}\frac{t^2}{a^2} + \frac{3}{16}\frac{t^4}{a^4} + \frac{t^6}{448a^6}\right)\right\}\Bigg] \tag{2}$$

If the two coils are alike and if $u=0$, this formula becomes the same as Equation (4) in the former article referred to.(1)

The component of force parallel to the axes is obtained by taking the partial derivative of Formula (1) with respect to u; and is, in pounds for one ampere in each coil:

$$F_u = \frac{\pi^2 A^2 a^2 N_1 N_2}{4.45 \times 10^7 B b}\Bigg[\left(\frac{u+m}{G_1^3} - \frac{u-n}{G_2^3} - \frac{u+n}{G_3^3} + \frac{u-m}{G_4^3}\right)$$
$$\left(1 + \frac{T^2}{12A^2}\right)\left(1 + \frac{t^2}{12a^2}\right)$$
$$- \frac{3}{8}\left\{2\left(\frac{u+m}{G_1^5} - \frac{u-n}{G_2^5} - \frac{u+n}{G_3^5} + \frac{u-m}{G_4^5}\right)\right.$$
$$\left. - 5s^2\left(\frac{u+m}{G_1^7} - \frac{u-n}{G_2^7} - \frac{u+n}{G_3^7} + \frac{u-m}{G_4^7}\right)\right\}$$
$$\left\{A^2\left(1 + \frac{T^2}{2A^2} + \frac{T^4}{80A^4}\right)\left(1 + \frac{t^2}{12a^2}\right)\right.$$
$$\left. + a^2\left(1 + \frac{T^2}{12A^2}\right)\left(1 + \frac{t^2}{2a^2} + \frac{t^4}{80a^4}\right)\right\}$$
$$+ \frac{5}{64}\left\{8\left(\frac{u+m}{G_1^7} - \frac{u-n}{G_2^7} - \frac{u+n}{G_3^7} + \frac{u-m}{G_4^7}\right)\right.$$
$$- 56s^2\left(\frac{u+m}{G_1^9} - \frac{u-n}{G_2^9} - \frac{u+n}{G_3^9} + \frac{u-m}{G_4^9}\right)$$
$$\left. + 63s^4\left(\frac{u+m}{G_1^{11}} - \frac{u-n}{G_2^{11}} - \frac{u+n}{G_3^{11}} + \frac{u-m}{G_4^{11}}\right)\right\}$$
$$\left\{A^4\left(1 + \frac{5}{4}\frac{T^2}{A^2} + \frac{3}{16}\frac{T^4}{A^4} + \frac{1}{448}\frac{T^6}{A^6}\right)\left(1 + \frac{t^2}{12a^2}\right)\right.$$
$$+ 3A^2a^2\left(1 + \frac{T^2}{2A^2} + \frac{T^4}{80A^4}\right)\left(1 + \frac{t^2}{2a^2} + \frac{t^4}{80a^4}\right)$$
$$\left. + a^4\left(1 + \frac{T^2}{12A^2}\right)\left(1 + \frac{5}{4}\frac{t^2}{a^2} + \frac{3}{16}\frac{t^4}{a^4} + \frac{1}{448}\frac{t^6}{a^6}\right)\right\}\Bigg] \tag{3}$$

where $m = \frac{B+b}{2}$ and $n = \frac{B-b}{2}$.

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(3) See Equation (2), "Repulsion and Mutual Inductance of Reactance Coils with the Same Axis," by H. B. Dwight, *Electric Journal*, May, 1918, p. 167.

If the instantaneous or direct currents in the two coils are i_1 and i_2 amp., multiply the expressions for force by $i_1 i_2$. If the r.m.s. currents in the two coils are I_1 and I_2, and if they have sine wave form and differ in phase by an angle θ, multiply the expressions by $I_1 I_2 \cos\theta$ for the average force or the steady push. Since Formulas (2) and (3) involve ratios of dimensions, the dimensions may be all in inches or all in centimeters. To express the force in grams, use the constant 981×100 in the denominator instead of 4.45×10^7.

Example 2: Same data as in Example 1.

$I_1 = 9.54$ amp., $I_2 = 2.46$ amp., direct current.

$$F_u = \frac{\pi^2 \times 3.08^2 \times 4.635^2 \times 1142 \times 516 \times 9.54 \times 2.46}{98{,}100 \times 5.62 \times 0.95} \Big(3.5 + 1.6 + 0.5 + 0.1\Big) 10^{-4}$$

$$= 30 \text{ grams.}$$

The fourth term in the bracket is estimated.

This force was measured by fastening one coil to a balance arm and adding weights to balance the force exerted when current was flowing. The measured force was 35 grams.

Example 3: This example illustrates the use of the formulas with two unequal reactance coils of dimensions such as might be encountered in practical engineering. Dimensions are in inches.

Large coil,

$A_1 = 26.1,\ A_2 = 38.1,\ B = 80$

Small coil,

$a_1 = 5,\ a_2 = 9,\ b = 10,\ s = 59.5,\ u = 31.$

Force perpendicular to the axes,

$7.9\ N_1 N_2\ I_1 I_2 \times 10^{-10}$ pounds.

Force parallel to the axes,

$10.0\ N_1 N_2\ I_1 I_2 \times 10^{-10}$ pounds.

Mutual inductance,

$2.4\ N_1 N_2 \times 10^{-9}$ henrys.

Formulas (1), (2), and (3) are indeterminate when B or b is equal to zero. In such cases, fewer integrations are needed and the results are given by shorter expressions. Such an expression can be obtained for the mutual inductance of a reactance coil of mean radius a and a single turn of fine wire of radius A, the axes being parallel. By dividing by πA^2 and then putting $A = 0$ in the resulting expression, the component of flux density parallel to the axis of the reactance coil is obtained. The expression for this component is as given in Equation (4) which follows:

$$\begin{aligned} B_u = \frac{\pi N I}{0.3937 \times 10 b} \Bigg[& \left(1 + \frac{t^2}{12a^2}\right) \left\{ \frac{a^2}{q^2} \mu_1 - \frac{a^2}{r^2} \mu_2 \right\} \\ & - \frac{3}{4} \left(1 + \frac{t^2}{2a^2} + \frac{t^4}{80a^4}\right) \left\{ \frac{a^4}{q^4} \left(\frac{5}{2} \mu_1^3 - \frac{3}{2} \mu_1 \right) \right. \\ & \left. - \frac{a^4}{r^4} \left(\frac{5}{2} \mu_2^3 - \frac{3}{2} \mu_2 \right) \right\} \\ & + \frac{3.5}{4.6} \left(1 + \frac{5}{4} \frac{t^2}{a^2} + \frac{3}{16} \frac{t^4}{a^4} + \frac{t^6}{448a^6}\right) \\ & \left\{ \frac{a^6}{q^6} \left(\frac{7.9}{2.4} \mu_1^5 - \frac{5.7}{2.2} \mu_1^3 + \frac{3.5}{2.4} \mu_1 \right) \right. \\ & \left. - \frac{a^6}{r^6} \left(\frac{7.9}{2.4} \mu_2^5 - \frac{5.7}{2.2} \mu_2^3 + \frac{3.5}{2.4} \mu_2 \right) \right\} + \cdot \cdot \Bigg] \end{aligned} \quad (4)$$

lines per square inch, where

$$q^2 = s^2 + \left(u - \frac{b}{2}\right)^2$$

$$r^2 = s^2 + \left(u + \frac{b}{2}\right)^2$$

$$\mu_1 = \frac{1}{q}\left(u - \frac{b}{2}\right)$$

$$\mu_2 = \frac{1}{r}\left(u + \frac{b}{2}\right)$$

The dimensions are assumed to be in inches. If they are in centimeters, the factor 0.3937 should be omitted, and the result will then be in lines per sq. cm.

Note that the brackets following $\frac{a^n}{q^n}$ and $\frac{a^n}{r^n}$ are zonal harmonics. Formula (4) can be readily extended and tables can be used. (See "*Fourier's Series and Spherical Harmonics,*" by W. E. Byerly, First Edition, pages 151 and 280.) The first bracket of each term is

$$\left\{ \left(1 + \frac{t}{2a}\right)^n - \left(1 - \frac{t}{2a}\right)^n \right\} \frac{a}{n t}$$

where n is an odd number.

This formula covers a wide range because it applies to points in any direction from the coil and separated from it by a distance not less than about one radius.*

The formulas in this article each consist of three terms added together, the formulas all being convergent series. If the third term is not small compared with the preceding terms, the formulas should not be used for that particular case. The usual reason for such an occurrence is that the coils are too near together.

The numerical calculation of at least the first term of each of the formulas should be made with better than slide-rule accuracy, since the small difference of larger quantities is computed.

It is desired to make acknowledgment to Mr. F. H. Kierstead of the Transformer Engineering Department of the General Electric Co., Pittsfield, Mass., for his suggestion of this problem and advice regarding it. The calculations described were carried out in the Department of Electrical Engineering, Massachusetts Institute of Technology.

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*A formula for the axial component of the magnetic field near the axis of a cylindrical coil is given in Equation (31), page 225 of "*Absolute Measurements in Electricity and Magnetism,*" edition of 1921, by Andrew Gray. This formula is stated to be given as far as terms in y^2, where y is the same as s, the distance of the point considered, from the axis of the coil. It would be expected that the formula would be suitable for points where y is not too large, since y is in the numerator. Formula (27), from which Formula (31) is derived, is a power series in y. It may be noted that Formula (4) of the present article is suitable for large values of s, since s is in the denominators of the various terms.

The writers of the present article believe that the equations for r_1 and r_2 given with Equation (28), which are needed for use in Equation (31) should be $r_1^2 = a^2 + (x + l)^2$ and $r_2^2 = a^2 + (x - l)^2$. Only the 1921 edition should be used for Equation (31).

Industrial Electric Heating

PART XIV: THE THREE-PHASE ARC FURNACE (Cont'd)

By N. R. STANSEL
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THE elementary diagrams shown in Figs. 177 to 180 inclusive illustrate several methods of connecting reactors in furnace circuits. Only one phase of the three-phase circuit is shown. The common notation of the diagrams is:

R = primary reactor
M = main primary winding of transformer
E = extended winding
S = secondary winding of transformer
ΔH = tap connection for "high" voltage
ΔI = tap connection for "intermediate" voltage
$\text{Y}L$ = tap connection for "low" voltage
C = cover of transformer tank
T = primary terminal.

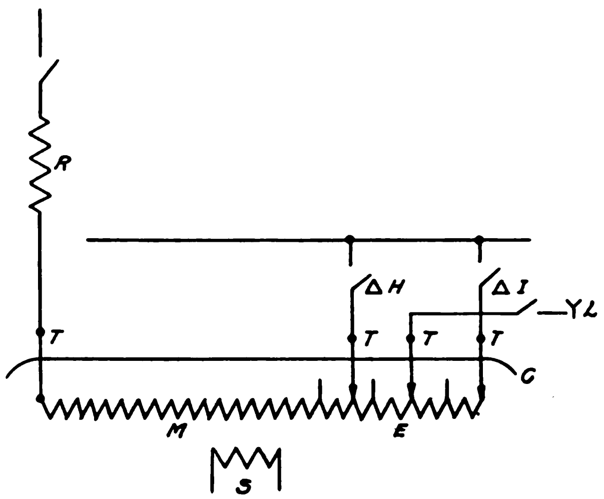

Fig. 177. Diagram of Furnace Transformer Circuit Showing External Primary Reactor in the Line. One phase only

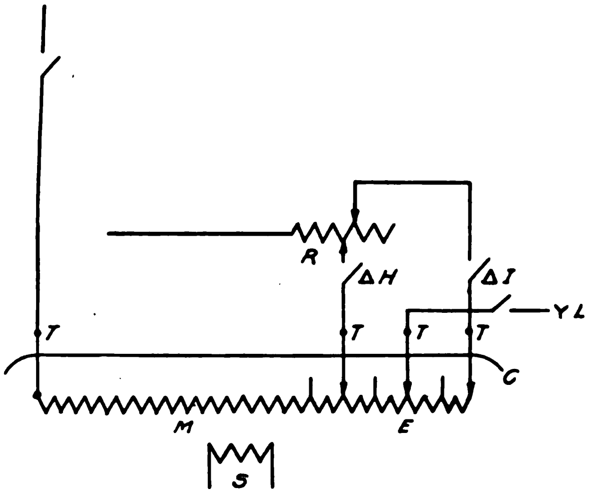

Fig. 178. Diagram of Circuit with External Primary Reactor Inside of the Delta Connection and Ahead of the Tap Switches

All of these diagrams of reactor connections indicate the use of the primary windings of the transformer in delta for the "high" and the "intermediate" operating voltages and the Y primary connection for the "low" operating voltage. The arrowheads indicate that connections are made to the particular taps desired in each case. All taps in the primary windings—and the taps in internal reactor windings where used—should be brought to a terminal board with terminals arranged for all combinations of tap connections which may be needed in each case.

In Fig. 177 the reactor is shown connected in the line ahead of the connections of the primary windings of the transformer. Fig. 178 shows the reactor inside the delta connection and ahead of the tap switches; with this arrangement the reactor is cut out of the circuit when the connections of the primary windings are changed from delta to Y. The connection of the reactor inside the delta as shown in Figs. 179 and 180 provides for the retention of the reactor in the circuit when the Y primary connection for the "low" operating voltage is made.

Taps in the reactor winding provide for the adjustment of the amount of supplemental reactance to be included in the furnace circuit. It is, of course, optional in each case whether the supplemental reactance is increased, decreased, or unchanged when a change in the operating voltage is made.

Reactors are specified to give a certain per cent reactive voltage drop in a circuit of a given kv-a. rating, voltage, and frequency. The kv-a. rating of a reactor is the product of the voltage drop across the reactor and

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The following table facilitates the location of material hitherto published in this serial

Part	*Issue*	*Figs.*	*Equations*	*Examples*	*Tables*	*Footnotes*
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Part II	Nov. 1927, p. 551	24 to 43	(9) and (10)	4 to 6	IV to VII	(3) to (13)
Part III	Dec. 1927, p. 600	44 to 57	(11) and (12)	8 to 11	VIII to IX	(14) and (15)
Part IV	Mar. 1928, p. 125	58 to 73	(13) and (14)	—	X to XX	(16) to (26)
Part V	Apr. 1928, p. 204	74 to 83	(15) to (21)	12 and 13	XXI to XXIII	(27) to (29)
Part VI	Sept. 1928, p. 485	85 to 99	—	14	XXIV to XXVI	(32) to (35)
Part VII	Oct. 1928, p. 560	100 to 113	(22) to (24)	15	XXVII and XXVIII	(36) to (41)
Part VIII	Dec. 1928, p. 662	114 to 138	(25)	—	—	(42) to (47)
Part IX	Mar. 1929, p. 162	139 to 144	(26) to (34b)	—	XXIX to XXXIII	(48) to (59)
Part X	May 1929, p. 278	145 to 150	(35) to (44)	—	XXXIV and XXXV	(60) to (65)
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Part XII	Feb. 1930, p. 123	155 to 162	(51) to (55)	16	XXXIX to XLI	(74) and (75)
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the rated current of the reactor. All other conditions being the same, the kv-a. rating of a reactor is the same whether it is connected in the line or inside the delta connection of the transformer windings. However, the voltage and the current relations differ for the two cases.

Let E = phase voltage of a three-phase circuit
I = line current
P = reactive voltage drop expressed as a decimal.

$$\text{Kv-a. of a line reactor} = \frac{E}{1.73} \times P \times I \qquad (56)$$

$$\text{Kv-a. of a delta reactor} = E \times P \times \frac{I}{1.73} \qquad (57)$$

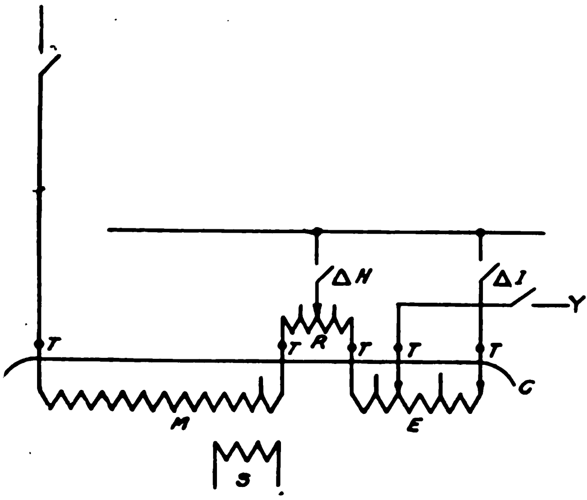


Fig. 179. Diagram of Circuit with External Primary Reactor Inside of the Delta Connection and Between the Main Winding and the Extended Winding

Thus the line reactor has a higher current rating and a lower voltage rating than a delta reactor for the same service. Hence the two types of reactors, although of the same kv-a. rating, are not interchangeable.

Example 17: (*a*) A reactor to be placed in the line and to give 35 per cent reactive drop in a 1500 kv-a. three-phase 25-cycle 2200-volt circuit.

$$I = 394 \text{ amp.}$$

$$\text{Kv-a. of reactor} = \frac{2200}{1.73} \times 0.35 \times 394$$
$$= 175 \text{ kv-a.}$$

Three reactors, each 175 kv-a., or a total of 525 kv-a., are required. As previously noted, either the single-phase or the three-phase construction for the reactor can be used.

(*b*). Same as (*a*) except that the reactor is to be connected inside the delta.

$$\text{Kv-a. of reactors} = 2200 \times 0.35 \times \frac{394}{1.73}$$
$$= 175 \text{ kv-a. per phase, as before.}$$

With a transformer in the furnace circuit the values of resistance and reactance which go to make up R and X in Equations (51) to (53) inclusive must be referred to either the primary or to the secondary side of the circuit. It is permissible for our purpose to neglect the effect of the magnetizing current of the transformer.

Considering the secondary side of the circuit, the value of the equivalent secondary reactance ohms of a primary reactor is

$$X_p' = X_p \left(\frac{E_s}{E_p}\right)^2 \qquad (58)$$

in which

X'_p = equivalent secondary ohms of a reactor in the primary side
X_p = reactance ohms of the primary reactor
E_s = secondary voltage, open circuit
E_p = applied primary voltage.

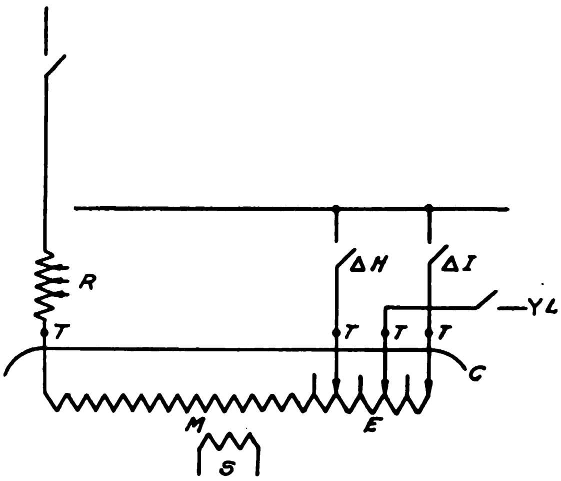


Fig. 180. Diagram of Circuit with Primary Reactor Inside of the Delta and Connected to the Main Winding at the End Opposite the Extended Winding

Example 18: $X_p = 10$ ohms
$E_s = 250$ volts
$E_p = 10{,}000$ volts

$$X_p' = 10 \left(\frac{250}{10{,}000}\right)^2$$
$$= 0.0062 \text{ ohm.}$$

Now if the taps in the primary windings of the transformer are changed to give another secondary voltage, say 200 volts, we will have a new value of X_p', *i.e.*,

$$X_p' = 10 \left(\frac{200}{10{,}000}\right)^2$$
$$= 0.0040 \text{ ohm.}$$

Thus for each ratio of turns of the transformer we have a corresponding value of the equivalent secondary ohms of a given primary reactance.

Considering the same tap connections for the Y connection as for the delta connection of the primary windings of the transformer, the change from delta to Y reduces the value X_p' of a reactor in the line, Fig. 177, to one-third of its value for the delta connection. This also applies to the reactance of the primary portion of the circuit. The delta-Y change noted does not affect the value X_p' if the reactor is connected inside the delta as shown in Figs. 179 and 180. The same conditions apply to the reactance of the transformer and to all primary resistance values. It will be noted that if practically all of the reactance of the furnace circuit is in the secondary side, as is the case in large furnace installations, the equipment operates at practically constant reactance for all operating voltages.

Although the resistance and the reactance of the transformer are usually comparatively small values it is well enough to include these values in the determination of the R and X of the furnace circuit. The secondary circuit values of the resistance and the reactance of the transformer are obtained as follows:

$$R_{ts} = \frac{\text{Load loss in watts}}{I^2} \qquad (58)$$

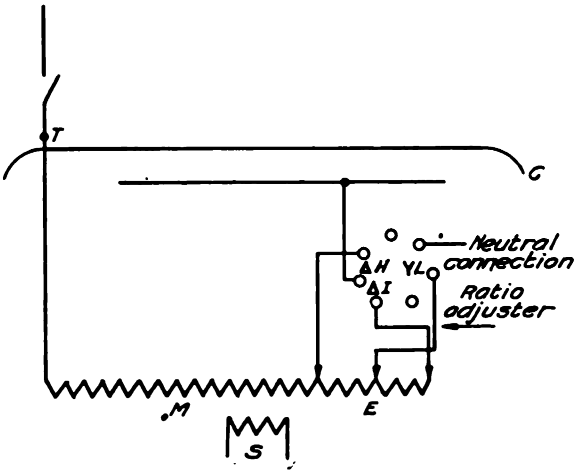


Fig. 181. Diagram of Connections of Ratio Adjuster for Three Operating Voltages. One phase only

in which

R_{ts} = secondary circuit resistance value in ohms per phase of the transformer

I = rated secondary current.

$$X_{ts} = \frac{P \times \text{kv-a. rating} \times 10^3}{I^2} \qquad (59)$$

in which

X_{ts} = secondary circuit reactance value in ohms per phase of the transformer

P = per cent reactive drop expressed as a decimal

I = rated secondary current.

Example 19: Assume that the load loss of the 4000 kv-a. transformer as obtained for Example 16 is 60 kw. at 10,500 amp. secondary current and that the reactive drop of the transformer with that current is seven per cent.

$$R_{ts} = \frac{60{,}000}{(10{,}500)^2}$$

$$= 0.00054 \text{ ohm}$$

$$X_{ts} = \frac{0.07 \times 4000 \times 10^3}{(10{,}500)^2}$$

$$= 0.00252 \text{ ohm.}$$

The diagrams of Figs. 169 and 170 and 177 to 180 inclusive indicate the use of switches outside of the transformer tank for changing the primary tap connections. The number of primary terminals per phase for three operating voltages for this method of switching is shown in the diagrams. For two operating voltages, one less primary terminal per phase would be required. If the "low" voltage is either the "high" voltage divided by 1.73 or the "intermediate" voltage divided by 1.73, the primary terminal for the Y connection is not needed. This, however, is not a flexible arrangement as it limits the selection of the "low" voltage to one of two values. The furnace transformer illustrated in Fig. 171 has four primary terminals per phase—a total of twelve—for external switching of tap connections and the use of three operating voltages.

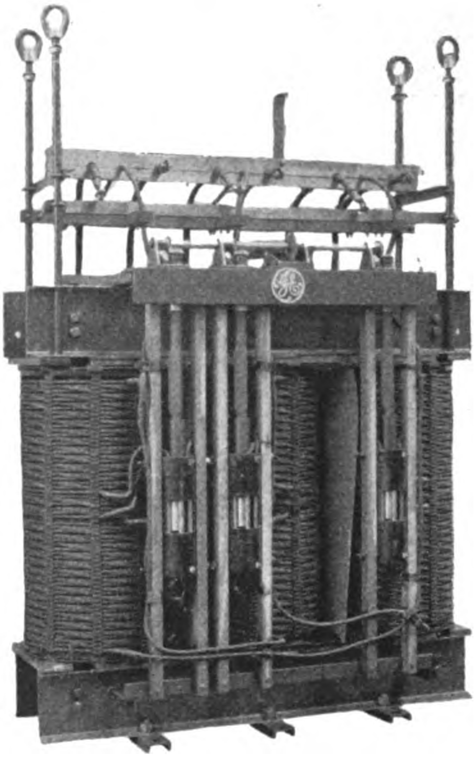


Fig. 182. Interior View of Three-phase Transformer, Showing Gear Connections of Ratio Adjusters

The general practice for external switching of tap connections is the use of oil circuit breakers. Disconnecting switches are used to some extent. In all cases a main-line oil circuit breaker should be installed. The tap switches should be interlocked to prevent short circuits and in addition interlocked with the main oil circuit breaker so as to render the tap switching equipment inoperative except when the main oil circuit breaker is open. The tap switches open and close the three-phase connections of the transformer primary windings. It is important that this switching be done only when the supply circuit of the transformer is open. Otherwise the tap switch will open (or close) the magnetizing current of the transformer.

In the operation of a switching device it is not probable that the contacts of all poles will open (or close) at the same instant. Hence if the tap-switching equipment opens or closes the magnetizing current the transformer will operate for a certain length of time—a small fraction of a second—with single-phase magnetizing current. Such operations give rise to high transient voltages which may exceed the strength of the insulation of some part of the circuit.

In the selection of tap-switching equipment, due consideration should be given to the auto-transformer effect of the extended winding of the transformer and of the primary reactor if the latter is connected inside the delta.

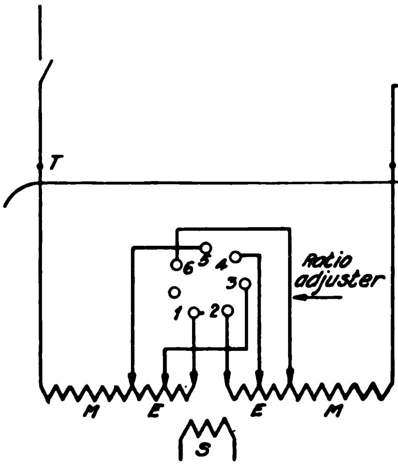


Fig. 183. Diagram of Connections of Ratio Adjuster for the "High" and "Intermediate" Operating Voltages and of External Switches for the "Low" Operating Voltage. One phase only

The sequence of operation of the tap-changing switches is generally "high," "intermediate," and "low." In some cases it is desirable to start the furnace with the "intermediate" voltage. This reduces the current fluctuations during the initial period of the heat cycle as compared with the fluctuations obtained with the use of the "high" voltage for starting the heat.

The diagram in Fig. 181 shows an application of the ratio adjuster to tap changing for three operating voltages. Three ratio adjusters, one for each phase, are required. These are geared together for simultaneous operation as shown in Fig. 182. The ratio adjuster is adapted to the use of a much larger number of operating voltages than is practicable with external switches. This device can be used with any of the methods of connecting reactors in the furnace circuit.

When a ratio adjuster is connected to the end of the transformer winding as indicated in Fig. 181, the insulation of its mechanism must correspond to the insulation of the end turns of the winding, *i.e.*, the voltage rating of the ratio adjuster is higher than the rated voltage of the circuit. A second method of applying the ratio adjuster to this service is its use for obtaining only the "high" and the "intermediate" operating voltages. The "low" voltage is obtained by using external switches to change the primary windings from delta to Y. In this case the ratio adjuster is connected to taps in the center section of the primary winding, as is standard practice for power transformers. The diagram for this arrangement is shown in Fig. 183.

The load ratio control equipment is also applicable to tap changing for furnace service. This requires two sets of ratio adjusters as shown in Fig. 184. With this equipment the power supply circuit is not opened for the tap-changing operation as is necessary with all other types of tap-switching equipment.

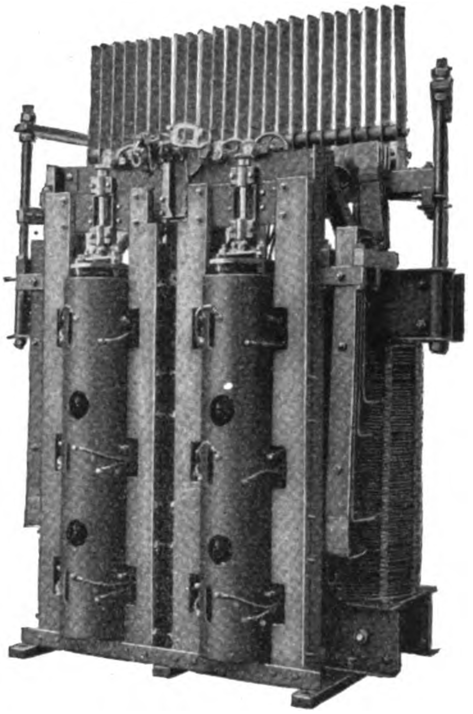


Fig. 184. Interior View of Three-phase Transformer with Ratio Adjusters for Load Ratio Control. Motor-operated mechanism

Electrical operation of the primary switching equipment of furnace installations is the rule, because of the convenience of electrical operation, of the freedom in the installation of the electrical apparatus, and of the simplicity of electrical interlocking. Manually operated mechanism is available for each type of switching equipment. Fig. 185 shows a transformer equipped with ratio adjusters and with an operating hand-wheel located for floor-level operation. There is considerable flexibility as to the location of this hand-wheel. A drum switch on the shaft of the operating mechanism provides contacts for electrical interlocking with the main oil circuit breaker so that the ratio adjuster is inoperative except when the main-line oil circuit breaker is open. The load ratio control equipment of Fig. 184 is arranged for motor operation. In all cases, whatever may be the type of tap switching equipment, a convenient accessory is a group of indicating lamps to indicate the switch positions.

The power regulation of a three-phase arc furnace is obtained by adjustments of the lengths of the arcs so as to maintain constant the selected average value of current in each phase. (The electrodes are free to move up and down and are independently driven through winches by shunt-wound d-c. motors.) Each electrode is under the control of a contact-making ammeter which functions through contactors in the electrode motor circuit. Fig. 186 illustrates a three-element automatic electrode regulator. The auxiliary push-button panel shown in Fig. 187 provides for hand operation of the electrode motors.

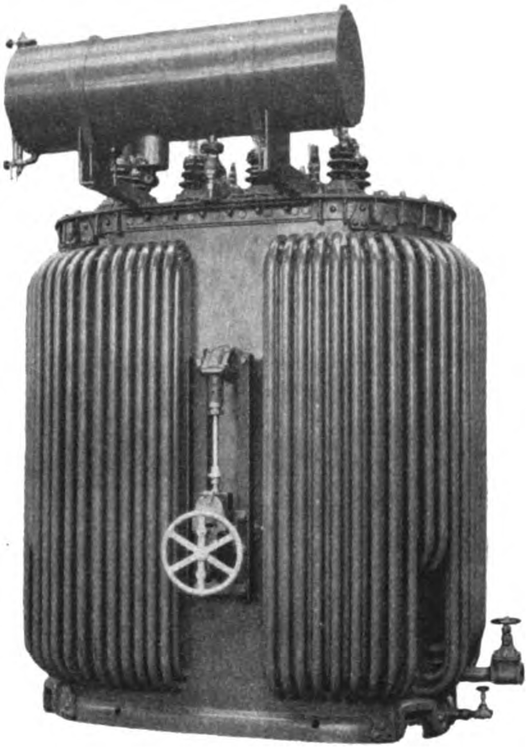


Fig. 185. Three-phase Transformer with Hand Wheel for Floor Level Operation of Ratio Adjusters

The elementary diagram of the circuits of the contact-making ammeters of the electrode regulator is given in Fig. 188. The regulating rheostat in parallel with the coil of the contact ammeter serves for the adjustment of the current in the furnace circuit.

Fig. 189 shows the elementary diagram of the circuits of the electrode motors. Resistor A limits the starting current to a safe value. Resistor B is inserted in the circuit by the lowering contactor thus giving a lower speed for the down movement of the electrode. Resistor C serves as a load for dynamic braking when the braking contact is closed by the opening of either the raising or the lowering contactor.

When the transfer switch on the auxiliary panel is moved to the position for automatic operation the speed regulating contactor closes and connects resistor D in parallel with the motor armature. This gives slower electrode speeds for automatic operation than for hand operation. Taps are placed in each of the resistors A, B, and D for adjustment of the electrode speeds to suit operating conditions.

A modification of this type of control is the use of adjustable speed electrode motors and a resistor (corresponding to resistor D) in the field circuit of the motor.

An a-c. undervoltage relay is connected in each phase of the furnace circuit, serving to prevent automatic lowering of the electrodes in case of a failure

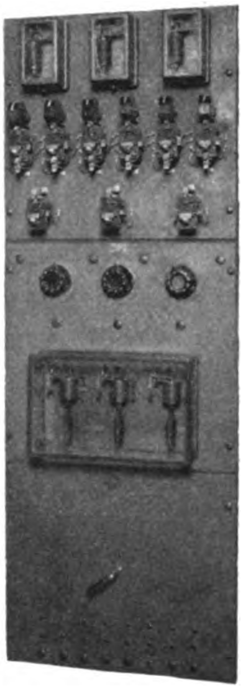


Fig. 186. Automatic Electrode Regulator for Three-electrode Arc Furnace

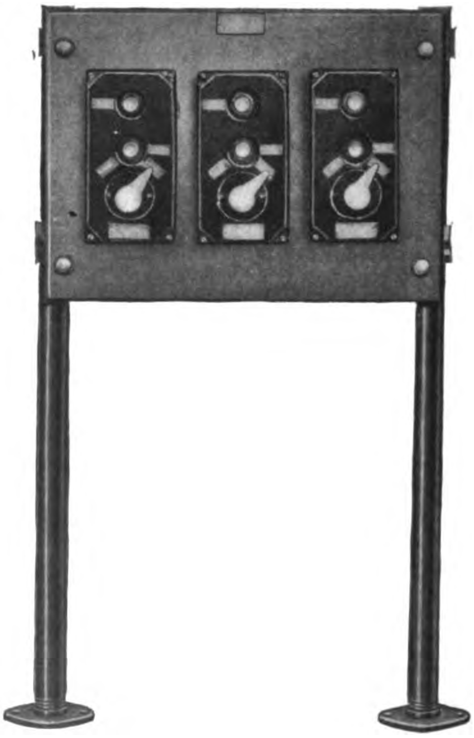


Fig. 187. Auxiliary Push-button Panel for Hand Operation of Electrode Motors

of the power supply. The relays are connected Y and the common terminal can be connected to the furnace shell, thus placing each relay across its respective arc. If the furnace lining is an electrical conductor—as is the case with a basic lining—this neutral connection makes the relays function to prevent the lowering of the electrodes into the charge during the automatic operation of the electrode regulator. The lining of acid furnaces is an electrical insulator. With these linings it is necessary to insert a metal electrode through the lining for electrical contact between the furnace shell and the charge in order to obtain this last-named function of the under-voltage relays.

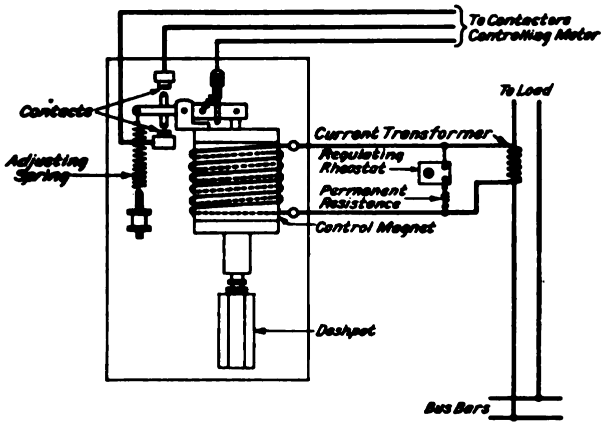


Fig. 188. Diagram of Connections of Contact-making Ammeter, Regulating Rheostat, and Current Transformer

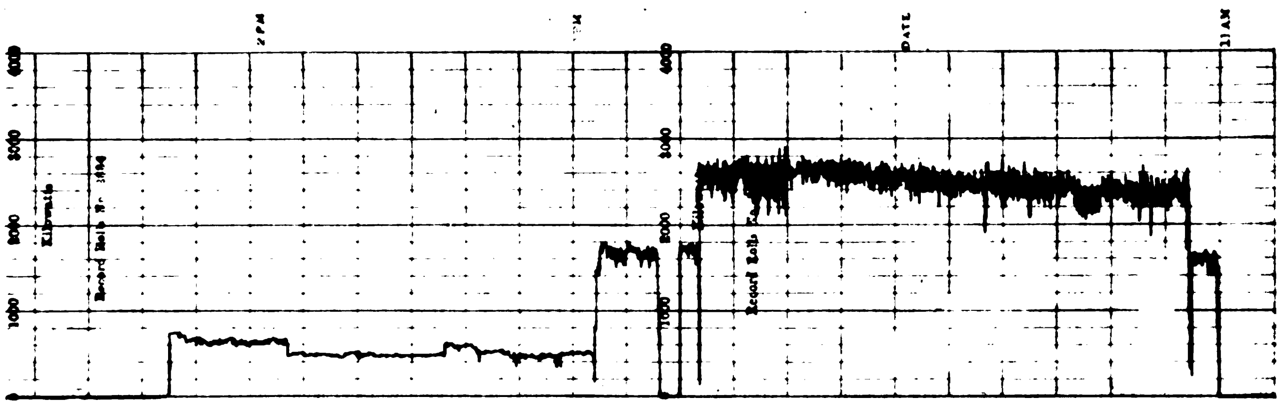


Fig. 190. Wattmeter Chart of a 2500-kv-a. Three-phase Arc Furnace Controlled by an Automatic Electrode Regulator

This description of the essential features of the automatic regulator follows general practice for steel melting furnaces. Various modifications of and additions to the regulator are made to suit special operating conditions.

The wattmeter chart in Fig. 190 is a typical record of the automatic power regulation of a basic lined three-phase arc furnace. The automatic electrode regulator operates jointly with the impedance of the furnace circuit in the power regulation of the furnace circuit. The higher this impedance—mainly reactance in a well designed furnace circuit—the less is the work imposed on the electrode regulator and *vice versa*. This is another consideration to be taken into account in the determination of the supplemental reactance required for a given furnace circuit.

Standard-type shunt-wound d-c. motors are used to drive the electrodes. In addition to requirements of torque and speed, these motors must have commutating capacity sufficient for dynamic braking with the desired maximum electrode speed.

The essential instruments for the electrical operation of a three-phase arc furnace are three ammeters—one for each phase—and an indicating wattmeter (see Fig. 162). The wattmeter should indicate the power input to the furnace and not the power input to the circuit. The difference between the power input to the circuit and the power input to the furnace for any given current is the value of the power loss of the circuit for that current. The larger this power loss the more important it is to distinguish between these two power input values.

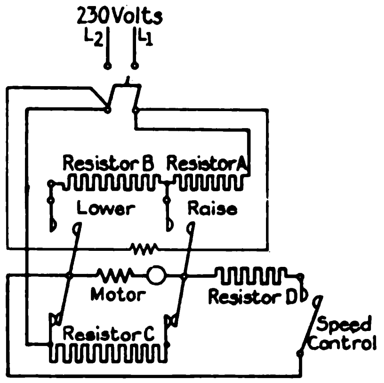


Fig. 189. Diagram of Electrode Motor Circuit

Other instruments are frequently included as particular needs dictate. A secondary voltmeter serves as a check on the supply voltage. A curve-drawing instrument—ammeter or wattmeter—gives a graphic record of the operation of the furnace. As the phases are unbalanced a large part of the time, a power-factor indicator is not very useful. Instruments for this service should be well damped but this should be accomplished without impairment of the accuracy of the indications.

A watthour meter in the primary circuit is needed for an integrated record of the energy used by the furnace installation. A reset dial is a useful addition to this meter. A watthour meter with this feature is shown in Fig. 191. The reset dial should be calibrated to register a number of kilowatt-hours per revolution somewhat more than the energy required per heat. Usually about one-third more is sufficient. The reset dial is independent of the standard dial registers of the meter. It is designed to be reset, *i.e.*, returned to zero, at the start of each heat.

The installation of current transformers in circuits of 10,000 amp. and higher is often a difficult problem. Two alternate methods are in use: first, the installation of current transformers in the circuit of one coil of each phase of the transformer secondary circuit; second, the use of current transformers in the primary circuit. Each case of this kind must be given individual consideration with respect to the

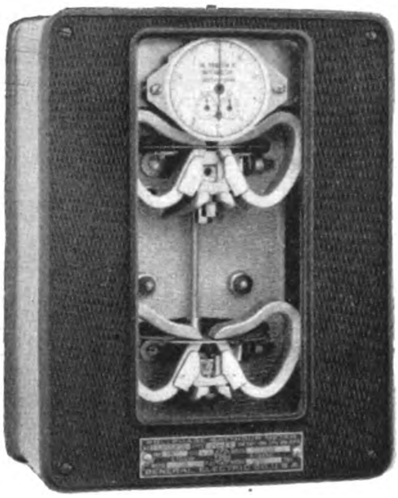


Fig. 191. Watthour Meter with Reset Dial

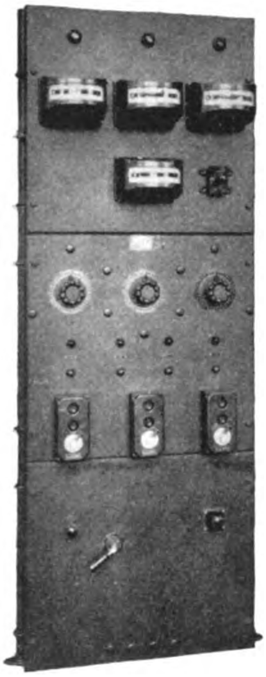


Fig. 192. Operator's Panel for a Three-phase Arc Furnace

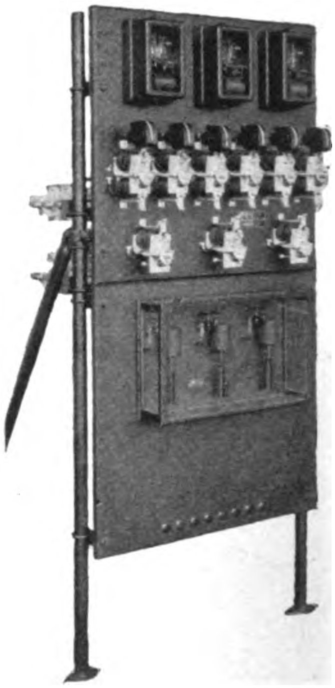


Fig. 193. Automatic Electrode Regulator for Use with Operator's Panel Shown in Fig. 192

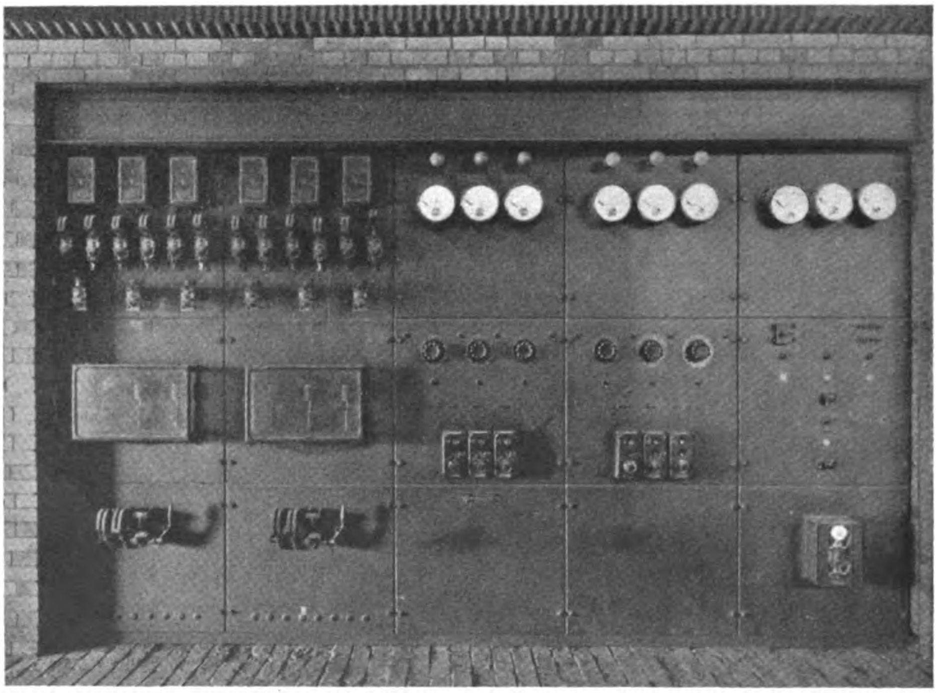


Fig. 194. Automatic Electrode Regulators and Operator's Panel of a 20,000-kv-a. Three-phase Arc Furnace

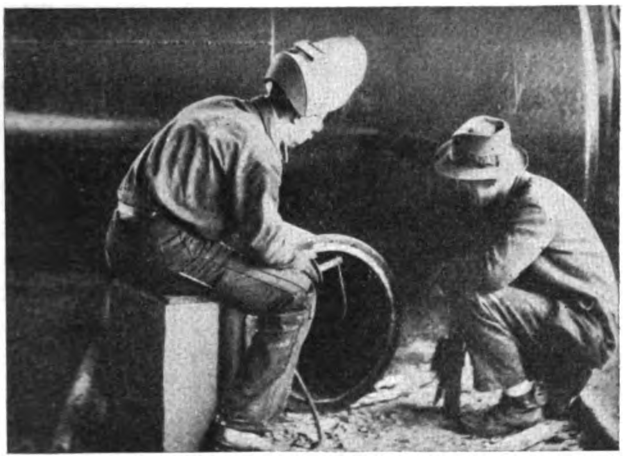
multiplying constants, taps in the windings of the main transformer, method of connecting the main transformer winding, etc. With primary current transformers it is usual practice to neglect the error introduced by the magnetizing current of the main transformer.

A convenient operator's panel for an arc furnace installation is shown in Fig. 192. This panel is designed for electrically operated switching equipment. A drum-type switch controls all switch movements. This control switch is so connected that the correct sequence of switch movements follows the rotation of the control switch to its position for the desired operating voltage. This type of panel includes, in addition to the instruments and meters and control switches, the three regulating rheostats of the automatic electrode regulator and the equipment of the auxiliary panel shown in Fig. 187. An automatic electrode regulator designed for use with an operator's panel of this type is shown in Fig. 193. This arrangement places the electrical control of the furnace at one point and permits the installation of the automatic electrode regulator in any convenient position.

An installation photograph of the automatic electrode regulators and operator's panels of the 20,000-kv-a. arc furnace installation shown as the frontispiece of the May number of this magazine is reproduced in Fig. 194.

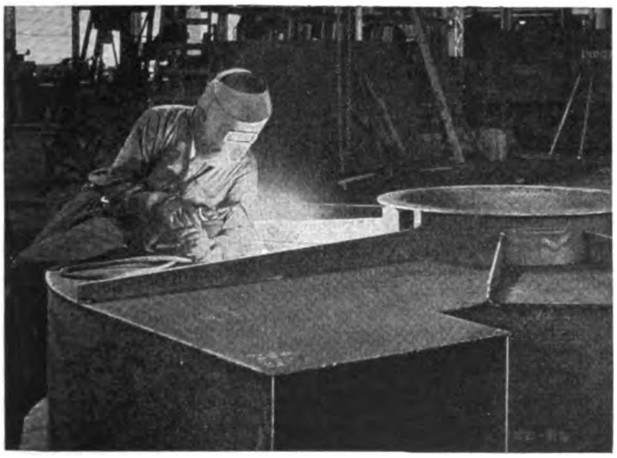
(To be continued)

Welders and Some of Their Work

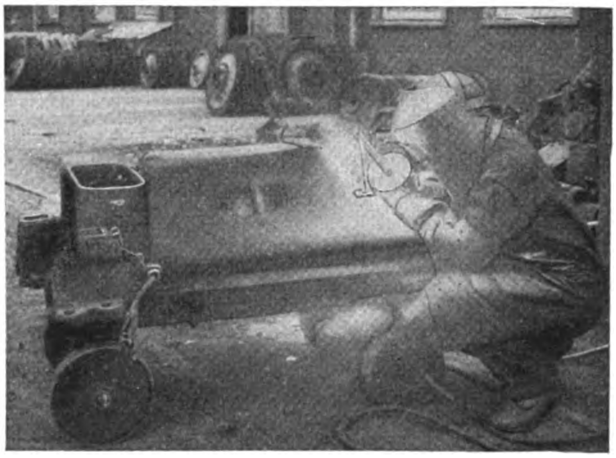


Tanks and Boiler Shells

Siphon-header Joints



Exhaust-fan Housings



Repairing Motor Frames

A Study of Crystal Structure and Its Applications

PART XV

CALCULATION OF THE ORIENTATION FROM SYMMETRICAL LAUE PHOTOGRAPHS

By DR. THOMAS A. WILSON
Research Laboratory, General Electric Company
Department of Chemistry, Union College, Schenectady

IN determining the orientation of large single crystals by the use of high-voltage x-rays, the mathematical and geometrical procedure is simplified by the use of Laue photographs possessing some degree of symmetry. Since there is a comparatively small chance that the first photograph obtained from a single-crystal specimen will be symmetrical, a number of photographs must usually be obtained from each specimen. To shorten the time necessary to obtain these photographs, high-voltage x-rays are of valuable assistance because of their greater penetration.

The first step in solving a symmetrical Laue photograph is to identify a zone of reflections on the film. The procedure involved has been described in Part XIV. If only an approximate determination of the crystal orientation is desired, a graphical method of proceeding from this point can be easily devised. This method is, essentially, an adaptation of that described by Wyckoff (186) and Ott. (187) The gnomonic projection of the film is drawn on transparent paper. Over this are laid transparencies of the Hilton rotation net (Fig. 87) and the standard gnomonic projection of Fig. 101, Part XIV, if the material under investigation belongs to the body-centered modification of the cubic system. In any case a standard gnomonic projection of the particular system under investigation must be provided. With a suitable means of illuminating these three transparencies from beneath, they may be rotated about their common center until the zone which has been identified from the film, the corresponding zone on the standard gnomonic projection, and the γ-lines of the rotation net are parallel. The problem is now reduced to that of ascertaining from the rotation net the amount of rotation necessary to bring the plotted zone to identity with the zone on the standard projection.

This approximate use of the data which can be obtained from x-ray exposures does not make full use of the possibilities inherent in this method of orientation determination. The optical methods of determining orientation may not give results quite so precise, but they are so much faster in their operation than the x-ray methods that there should be no competition between the two procedures if approximate results only are desired. In convenience, too, the optical methods are superior. The gnomonic projections demanded by this method of solving the x-ray pattern are of prohibitive size if the customary crystal-projection distance of 5 cm. is used. Although the writer has used satisfactorily projections drawn to half this scale, these projections were still uncomfortably large.

In the precise determination of crystal orientation, however, the x-ray methods are supreme. Any Laue photograph, whether symmetrical or not, can be solved so that the orientation of the crystal which produced it can be obtained. Because of the relative simplicity of the calculations applying to symmetrical photographs, these calculations will be described first. The calculations will also be considered primarily with reference to the cubic system. In this system, two cases must be considered; in the first case, the symmetrical photograph has been obtained by rotation of the crystal into the $\{100\}$ system of zone axes; in the second case, the rotation has been into the $\{110\}$ system. In both cases, it will be supposed that the identity of some zone of plane reflections has been established.

Rotation Into the $\{100\}$ System of Axes

Consider a section of the standard gnomonic projection for a crystal belonging to the cubic system. In Fig. 106, *AB* and *CD* are respectively the lines $h=0$ and $k=0$ of this projection, intersecting at *E*. This is, therefore, the location of the $(001)_1$ spot, the subscript referring to the occurrence of the spot in this position on the standard projection. Let *FG* be some zone occurring on a symmetrical Laue photograph of a single crystal. The identity of this zone has been established by the method previously described. On the standard projection, this zone intersects the line *AB* at *T*. This distance *ET* along the $h=0$ axis corresponds to the angle γ_1 (Fig. 87). For convenience the directions along which the angles δ and γ and the lengths ζ and ξ apply have been indicated on the projection.

The position of the zone *FG* when plotted gnomonically from the symmetrical Laue photograph is the line *HK*, which cuts the *AB* axis at *U*. This distance *EU* corresponds to a second value of γ, which is called γ_2. Let the difference $\gamma_2-\gamma_1$ be denoted by $\Delta\gamma$, the amount of the rotation of the crystal referred to its standard position.

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(186) R. W. G. Wyckoff, "The Structure of Crystals," *Chemical Catalog Co.*, N. Y., 1924, pp. 133-136.

(187) H. Ott, *Handbuch der Experimental Physik*, Vol. 7, Pt. 2, *Akedemische Verlagsgesellschaft, Leipzig* (1928), pages 216 ff.

Although five projections of the form (100) are to be found on the standard gnomonic projection (four of them occurring at infinity) only three of them will be of value in determining the orientation of the crystal; namely, those which intercept the plane of the gnomonic projection in the initial position of the crystal. It is possible to tell from the Laue photographs what projections these will be. In the present case, let these projections be those corresponding to the (001), (010), and the (100) planes.

The β, γ coördinates of these projections in the standard position of the crystal can be found by inspection. These may be written as:

$$\beta_{(001)\ (1)} = 0^\circ \qquad \gamma_{(001)\ (1)} = 0^\circ$$
$$\beta_{(010)\ (1)} = 0^\circ \qquad \gamma_{(010)\ (1)} = 90^\circ$$
$$\beta_{(100)\ (1)} = 90^\circ \qquad \gamma_{(100)\ (1)} = 0^\circ$$

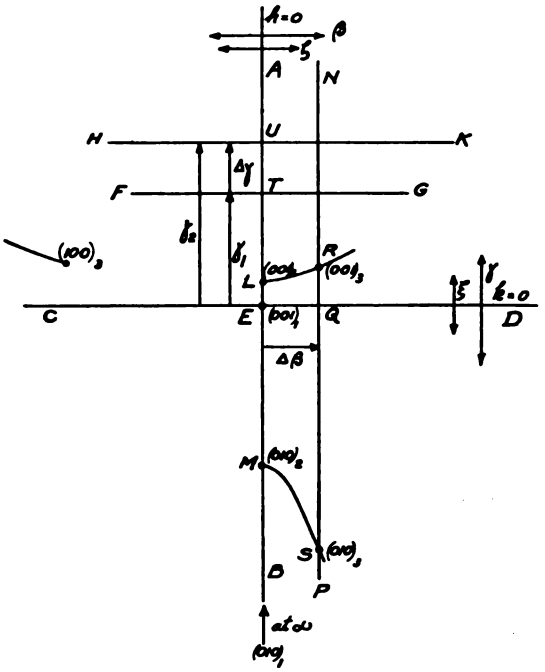

Fig. 106. Gnomonic Representation of Rotation Along $h=0$, Followed by Rotation Along $k=0$

In order that the zone *FG* may be brought into coincidence with *HK*, the standard gnomonic projection must be rotated by an amount $\Delta\gamma$. Let the crystal-projection distance be denoted by R. During this rotation, the projections will move along hyperbolas of the form:

$$\xi = R \tan \gamma \qquad (95)$$

$$\zeta = R \tan \beta \sec \gamma \qquad (96)$$

During this rotation, β (and hence $\tan \beta$) is constant. The positions of the projections when the requisite rotation has been given to the standard gnomonic projection will be therefore:

$$\xi_{(001)\ (2)} = R \tan \Delta\gamma \qquad \zeta_{(001)\ (2)} = R \tan 0 \sec \Delta\gamma = 0$$
$$\xi_{(010)\ (2)} = R \tan (\Delta\gamma - 90) \qquad \zeta_{(010)\ (2)} = 0$$
$$\xi_{(100)\ (2)} = R \tan \Delta\gamma \qquad \zeta_{(100)\ (2)} = R \tan (-90) \sec \Delta\gamma = -\infty$$

These are the ξ, ζ values of the [100] spots when the elementary cube has been rotated into the position shown on the symmetrical film.

To complete the problem the crystal must be rotated into the position shown by the original trial photograph, unless the trial photograph itself was symmetrical. It was shown in Part XIV that the line of symmetry will be perpendicular to the direction of rotation imparted to the specimen. Consequently, the rotation to be imparted to the specimen of Fig. 106 will lie along $k=0$. Let the amount of this rotation be the angle $\Delta\beta$.

At the conclusion of the previous rotation, the values of the three [100] projections were seen to be (in degrees):

$$\beta_{(001)\ (2)} = 0 \qquad \gamma_{(001)\ (2)} = \Delta\gamma$$
$$\beta_{(010)\ (2)} = 0 \qquad \gamma_{(010)\ (2)} = \Delta\gamma - 90$$
$$\beta_{(100)\ (2)} = -90 \qquad \gamma_{(100)\ (2)} = \Delta\gamma$$

Owing to the change of the axis of rotation, the general Equations (95) and (96) must be changed to read:

$$\xi = R \tan \gamma \sec \beta \qquad (95a)$$

$$\zeta = R \tan \beta \qquad (96a)$$

During the rotation, the $(001)_2$ projection will move along its hyperbolic path until position $(001)_3$ is reached. Projection $(010)_2$ behaves similarly. Spot $(100)_2$ moves from infinity into the visible region and becomes $(100)_3$. Remembering that these hyperbolas are now lines of constant γ, and that the values of both $(100)_3$ and $(001)_3$ are identical, it is seen that the new ξ, ζ values of the projections are as follows:

$$\xi_{(001)\ (3)} = R \tan \Delta\gamma \sec \Delta\beta \qquad \zeta_{(001)\ (3)} = R \tan \Delta\beta$$
$$\xi_{(010)\ (3)} = R \tan (\Delta\gamma - 90) \sec \Delta\beta \qquad \zeta_{(010)\ (3)} = R \tan \Delta\beta$$
$$\xi_{(100)\ (3)} = R \tan \Delta\gamma \sec (\Delta\beta - 90) \qquad \zeta_{(100)\ (3)} = R \tan (\Delta\beta - 90)$$

The radial distance of each of these projections from the zero beam impression of the film is $\sqrt{\xi^2+\zeta^2}$ (Part XII). From the geometry of the gnomonic projection

$$\tan (90-\theta) = \cot \theta = \frac{\sqrt{\xi^2+\zeta^2}}{R} \qquad (108)$$

where θ is the angle existing between the plane and the x-ray beam. If the x-ray beam penetrates the specimen when the trial photograph is being obtained in a direction perpendicular to the surface of the specimen, then the angle $90-\theta$ is the angle existing between the plane perpendicular and the perpendicular erected to the surface of the specimen (Fig. 107). In the cubic system, the plane perpendiculars are parallel to the cube edges. Hence, although the results in any crystal system are as unique as they are in the cubic system, it is perhaps easier to visualize their significance in this system.

Substitution of the proper ξ, ζ values in Equation (108) gives at once the following values for tan $(90-\theta)$:

$$\left.\begin{aligned}\tan(90-\theta)_{(001)\,(3)} &= \sqrt{\tan^2\Delta\beta+\tan^2\Delta\gamma\sec^2\Delta\beta}\\ \tan(90-\theta)_{(010)\,(3)} &= \sqrt{\tan^2\Delta\beta+\tan^2(\Delta\gamma-90)\sec^2\Delta\beta}\\ \tan(90-\theta)_{(100)\,(3)} &= \sqrt{\tan^2(\Delta\beta-90)+\tan^2\Delta\gamma\sec^2(\Delta\beta-90)}\end{aligned}\right\}\quad(109)$$

Rotation Into the $\{110\}$ System of Axes

This case, somewhat more complicated than the preceding, seems to be the more usual one. In Fig. 108, as before, let AB and CD be the main axes of a gnomonic projection of the cubic system, with A' B' and C' D' the $\{110\}$ system of axes passing through the same common center E. Let A' B' be the line of symmetry in the Laue photograph. The zone FG denotes the position of a zone on the standard gnomonic projection which can be identified from the symmetrical photograph. On the symmetrical photograph, however, the zone appears at HK. The distance TU along EA' evidently corresponds to the amount of this rotation, or to the angle $\Delta\gamma$ $(=\gamma_2-\gamma_1)$ as shown. As a result of this rotation, $(001)_1$ moves into position $(001)_2$, and $(010)_1$ and $(100)_1$ move in from infinity along the hyperbolic traces shown to take up the positions $(010)_2$ and $(100)_2$ respectively. In the standard position of the crystal, the angles associated with each of these projections were as follows:

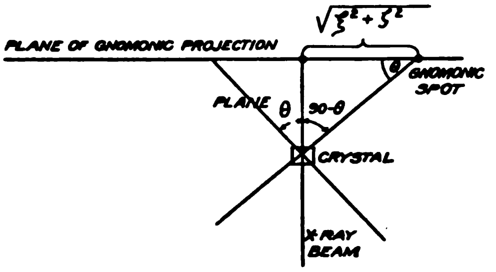

Fig. 107. Relation Between the X-ray Beam, Reflecting Plane, and the Gnomonic Projection of the Reflection

$$\begin{aligned}\beta_{(001)\,(1)}&=0 & \gamma_{(001)\,(1)}&=0\\ \beta_{(010)\,(1)}&=45^\circ & \gamma_{(010)\,(1)}&=-90^\circ\\ \beta_{(100)\,(1)}&=-45^\circ & \gamma_{(100)\,(1)}&=-90^\circ\end{aligned}$$

The values of these angles after the standard projection has been rotated to produce agreement of the identified zone with that on the symmetrical projection are:

$$\begin{aligned}\beta_{(001)\,(2)}&=0 & \gamma_{(001)\,(1)}&=\Delta\gamma\\ \beta_{(010)\,(1)}&=45^\circ & \gamma_{(010)\,(1)}&=\Delta\gamma-90\\ \beta_{(100)\,(1)}&=-45^\circ & \gamma_{(100)\,(1)}&=-\Delta\gamma-90\end{aligned}$$

since the hyperbolas of rotation are lines of constant β. The ζ values of the projections will therefore be:

$$\zeta_{(001)\,(2)}=R\tan 0\sec\Delta\gamma=0$$

$$\zeta_{(010)\,(2)}=R\tan 45\sec(\Delta\gamma-90)=R\sec(\Delta\gamma\text{-}90)$$

$$\zeta_{(100)\,(2)}=R\tan(-45)\sec(\Delta\gamma-90)=-\mathrm{R}\sec(\Delta\gamma-90)$$

The ξ values may be also obtained:

$$\left.\begin{aligned}\xi_{(001)\,(2)}&=R\tan\Delta\gamma\\ \xi_{(010)\,(2)}&=R\tan(\Delta\gamma-90)\\ \xi_{(100)\,(2)}&=R\tan(\Delta\gamma-90)\end{aligned}\right\}\quad(110)$$

In accordance with the previous procedure, the derived gnomonic projection which now agrees with the position of the crystal when the symmetrical photograph was taken, is to be rotated into the position agreeing with that of the trial photograph.

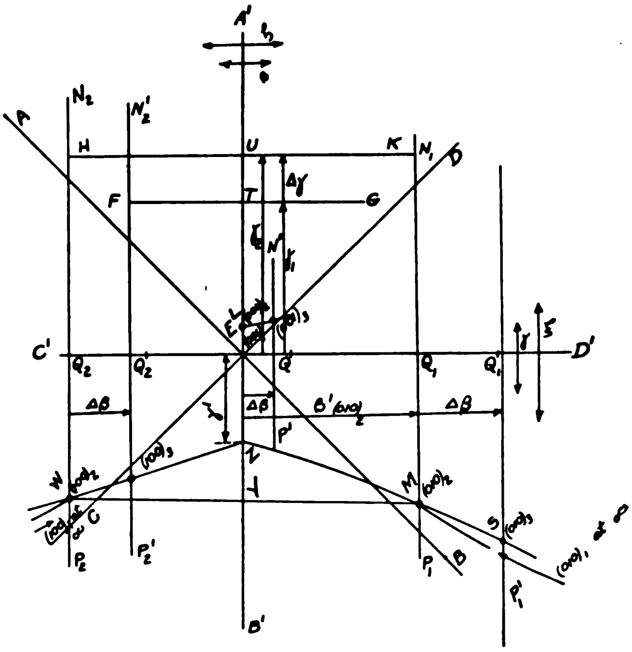

Fig. 108. Gnomonic Representation of Rotation Along $\{1\bar{1}0\}$ Followed by Rotation Along $\{\bar{1}10\}$

This means rotation along the line C' D', by an amount corresponding to the angle $\Delta\beta$. The generalized equations for rotation along this direction will be again Equations (95a) and (96a). During the rotation, $(001)_2$ becomes $(001)_3$, by moving along the hyperbolic trace shown. Similar behavior is also shown by each of the projections $(010)_2$ and $(100)_2$. It will furthermore be noticed that both of these latter projections are on the same zone, as shown by the connecting hyperbola.

In the ζ direction, each projection shows a different value. Consideration of the geometry of the gnomonic projection shows that:

$$\tan\beta'_{(001)\,(2)}=0$$

$$\tan\beta'_{(010)\,(2)}=\frac{EQ_1}{R}=\frac{\zeta_{(010)\,(2)}}{R}=\sec(\Delta\gamma-90)$$

$$\tan\beta'_{(100)\,(2)}=\frac{EQ_2}{R}=\frac{\zeta_{(100)\,(2)}}{R}=-\sec(\Delta\gamma-90)$$

After the rotation through the angle $\Delta\beta$ the following Equations result:

$$\left.\begin{aligned}\zeta_{(001)\,(3)} &= R\tan\Delta\beta\\ \zeta_{(010)\,(3)} &= R\tan\left[\Delta\beta+\tan^{-1}\sec(\Delta\gamma-90)\right]=R\tan(\Delta\beta+\beta')\\ \zeta_{(100)\,(3)} &= R\tan\left[\Delta\beta+\tan^{-1}-\sec(\Delta\gamma-90)\right]=R\tan(\Delta\beta-\beta')\end{aligned}\right\}\quad(111)$$

in which $\beta' = \tan^{-1}\sec(\Delta\gamma-90)$. (Fig. 109.)

To obtain the ξ values for the projections the value of γ in Equation (95a) must be found. By construction, $\gamma_{(001)\,(2)}=\Delta\gamma$ but the value of $\gamma_{(010)\,(2)}=\gamma_{(100)\,(2)}$ is not so clear. Consideration of the $(010)_2$ projection shows that:

$$\xi_{(010)\,(2)} = R\tan\gamma'\sec\beta' = R\tan(\Delta\gamma-90)$$

from Equation (110), and the substitution mentioned above. From the equation it can at once be shown that

$$\tan\gamma' = \frac{\tan(\Delta\gamma-90)}{\sec\beta'}$$

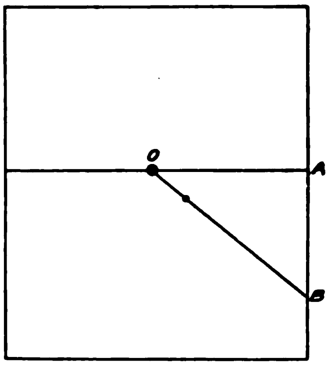

Fig. 109. Method of Obtaining Direction of Zone Axes

It is now possible to set up the ξ — value Equations for the [100] projections with the following result:

$$\left.\begin{aligned}\xi_{(001)\,(3)} &= R\tan\Delta\gamma\sec\Delta\beta\\ \xi_{(010)\,(3)} &= \frac{R\tan(\Delta\gamma-90)}{\sec\beta'}\sec(\Delta\beta+\beta')\\ \xi_{(100)\,(3)} &= \frac{R\tan(\Delta\gamma-90)}{\sec\beta'}\sec(\Delta\beta-\beta')\end{aligned}\right\}\quad(112)$$

With the Equations for the ξ, ζ values of the projections derived, it becomes possible to set up the expressions for the angles bounded by the plane perpendiculars (or the cube corners in the cubic system) and the perpendicular to the face of the specimen, if this coincides with the direction of the x-ray beam. Making the proper substitutions in Equation (100) and simplifying, the following equations are obtained:

$$\left.\begin{aligned}\tan(90-\theta)_{(001)\,(3)} &= \sqrt{\tan^2\Delta\beta+\tan^2\Delta\gamma\sec^2\Delta\beta}\\ \tan(90-\theta)_{(010)\,(3)} &= \sqrt{\tan^2(\Delta\beta+\beta')+\frac{\tan^2(\Delta\gamma-90)\sec^2(\Delta\beta+\beta')}{\sec^2\beta'}}\\ \tan(90-\theta)_{(100)\,(3)} &= \sqrt{\tan^2(\Delta\beta-\beta')+\frac{\tan^2(\Delta\gamma-90)\sec^2(\Delta\beta-\beta')}{\sec^2\beta'}}\end{aligned}\right\}\quad(113)$$

Fixing the Orientation About the Perpendicular Axis

By the use of the appropriate set of equations just given, it is possible to calculate the angles existing between the perpendicular and the face of the specimen (or the direction of the x-ray beam) and the face-plane-perpendiculars. While these results fix the orientation with respect to the perpendicular axis, they do not preclude the rotational motion of the cube about this axis. For this purpose further data are necessary.

Precise placement of the film with reference to the direction of the specimen is necessary in this part of the work. The most advantageous arrangement is to place the edge of the specimen parallel to the edge of the film. In this instance the directions of the angles, or distances, may be read off with reference to the edge or a perpendicular to the edge of the film, and transferred to the specimen without calculation. All the work of this nature which has been done in this laboratory has been done with this relationship existing between the edges of the films and the specimens.

The angles which are important in this work are the angles which the zone axes form with the edge of the specimen (or the side of the film). These are best obtained in the manner shown in Fig. 109. Through the center of the zero beam impression a line *OA* is scratched perpendicular to the edge of either the film or the specimen. If the film is symmetrical, a second line *OB* is scratched down the line of symmetry. If the unsymmetrical trial photograph is being used, the second line is scratched through the spot which causes symmetry when it is rotated into the zero beam. Some function of the angle *AOB* is now read off with the dividers and the angle determined. The cube whose orientation with respect to the perpendicular to the surface of the specimen has been determined is swung about on this perpendicular as an axis until its line of symmetry, or the line of its second direction of rotation, coincides with the line *OB* in direction.

Application to the Crystal of Silicon Steel of Figs. 104 and 105 (Part XIV)

The application of the preceding formulas to the determination of the orientation of an actual crystal will be shown. For this purpose, use will be made of the data of Part XIV, in which the zone on the symmetrical film was identified. The line of symmetry of this crystal shows the rotation to be along the $\{110\}$ axes. The projection of the $\bar{1}\bar{1}2$ spot is evidently in position *U* (Fig. 108). By measurement from the film and by calculation, its 2θ value is found to be 29° 14′, giving $\theta = 14°\,37'$, and $\gamma_2 = 90-\theta = 75°23'$. By calculation, according to Equations (106) and (107) (Part XIV), γ_1 (the angle between the (001) and the ($\bar{1}\bar{1}2$) projections) is 35° 16′. Therefore $\Delta\gamma$ is 40° 7′. From Fig. 105 (Part XIV) the angle between the zero beam impression and spot 2 is 5° 3′. From this, the value of $\Delta\beta$ is shown to be 87° 28′. This large value of the angle $\Delta\beta$ means that after the rotation along the C' D' line, $(001)_3$ will be situated at a great distance from the center of the projection, and $(010)_3$ will be off the plane of projection altogether. To simplify the situation, use is made of the symmetry characteristics of the crystal. Since this crystal is cubic, and the second rotation (like all of those employed in the calculations) is about a cube axis, the angle $\Delta\beta$ may be taken as the complement of the value given above, in the opposite direction. In the ensuing calculations, this has been done, and the value of $\Delta\beta = -2° 32'$. Since all terms in Equation (113) are squares, the signs of the first power terms may be neglected. Calculation shows the values of the $(90-\theta)$ angles to be 40° 4′, 64° 16′, and 64° 59′ for the $(001)_3$, $(100)_3$, and the $(010)_3$ plane perpendiculars respectively. Their ζ and ξ values are also easily obtained:

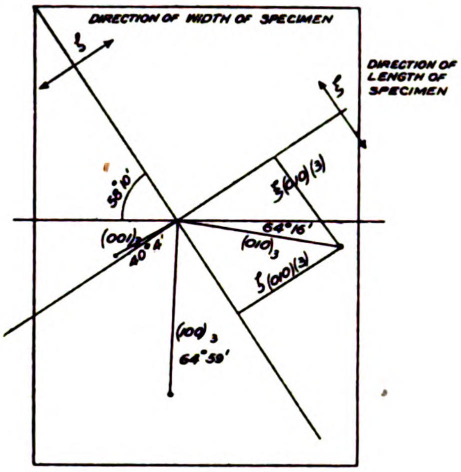

Fig. 110. Method of Plotting Projections of |100| Planes

	ζ	ξ
$(001)_3$	2.10	0.11
$(010)_3$	3.80	3.54
$(100)_3$	3.20	4.30

These values are in cm. on a projection drawn with a crystal-projection distance of 2.5 cm. From Fig. 105 (Part XIV), it is also possible to obtain the "angle of direction": the angle between the line of symmetry and one of the directions of the specimen. In this case, the angle between the line of symmetry and the direction of width of the specimen is 58° 10′, as shown in Fig. 110.

The ζ and ξ coördinates are now plotted. With the values of ζ and ξ at hand the projections of the cube faces can be located. As Fig. 111 shows, the drawing of the cube in its relationship to the specimen is then a simple matter.

Check of Results

One of the most useful checks of the results of these calculations for a rectangular parallelopiped is furnished by a study of the relationship of the angles existing between the corners of the parallelopiped and the plane on which it is resting. In Fig. 112 let these angles be denoted by A, B, and C. It is possible to show[188] that the following relation exists:

$$\sin^2 A + \sin^2 B + \sin^2 C = 1 \qquad (114)$$

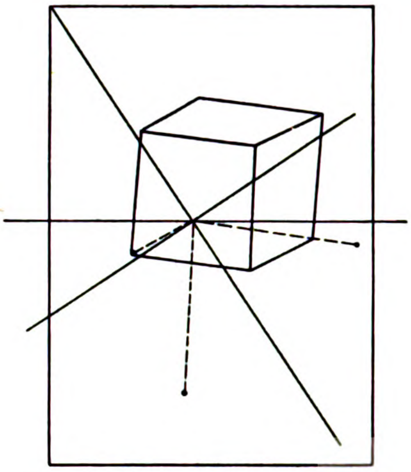

Fig. 111. Orientation of Silicon-steel Cube

This function reaches a minimum when one of the angles is 0, in which case,

$$A + B = 90°.$$

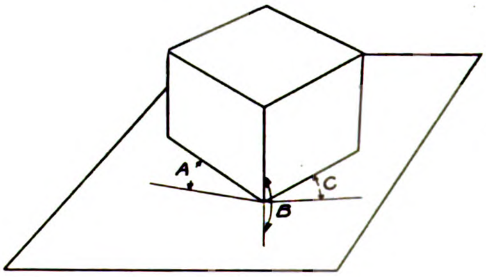

Fig. 112. Method of Checking Results

When $A = B = C$, the function reaches its maximum of 105° 48′. It is also clear from a consideration of the geometry of the system that

$$(90-\theta)_{(001)\,(3)} + (90-\theta)_{(010)\,(3)} + (90-\theta)_{(100)\,(3)} = 270 - (A+B+C).$$

In the present case, substituting the calculated values of the angles, $A+B+C = 100° 49'$, which is a reasonable value.

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[188] I am indebted to Prof. H. A. DoBell, of the Department of Mathematics, State College for Teachers, Albany, N. Y., for showing me this proof.

(To be continued)

The Charles A. Coffin Fellowship Awards for 1930-1931

IN accordance with the terms of the Charles A. Coffin Foundation, eight young men have been chosen by a committee as the recipients of fellowship awards permitting them, during the year 1930-31, to carry on research in the fields of engineering and modern physics and chemistry, at institutions of their choice.

The Foundation was established in honor of the late Charles A. Coffin, first president and chairman of the Board of Directors of the General Electric Company, and provides means to promote scientific investigations by deserving students who, without such encouragement and aid, would not be able to pursue their work without disadvantage.

The members of the committee making the awards this year were Gano Dunn, representing the National Academy of Sciences; R. I. Rees, representing the Society for the Promotion of Engineering Education; and Harold B. Smith, representing the American Institute of Electrical Engineers. Representing the General Electric Company were Dr. Willis R. Whitney, Vice President and Director of the Research Laboratory, and W. W. Trench, Secretary.

The young men to whom the awards were made are:

John S. V. Allen, a graduate of Ohio State University, receiving the degree of Bachelor of Engineering Physics in 1928. At present Mr. Allen is engaged in graduate work pursuant to an M.A. degree at Ohio State University. He has previously been employed in the Incandescent Lamp Department of the General Electric Company at Nela Park, Cleveland (O.). His anticipated work under the fellowship will be an investigation of the Zeeman Effect, and will be carried on in the Physics Department of the Ohio State University.

Edmund A. Evans, a graduate in Electrical Engineering of Rensselaer Polytechnic Institute in 1926. He is now engaged in graduate work at Stanford University in anticipation of the degree of Ph.D. in Electrical Engineering. Under the fellowship he will continue his work upon the development of a theory of thunderstorms explaining the ionization of clouds, the phenomena in cloud volume discharges, and the mechanism of a lightning stroke. Mr. Evans has been in charge of the lightning laboratory at Wallenpaupack (Pa.) making kindred investigations for the General Electric Company.

Ferdinand Hamburger, Jr., a graduate of Johns Hopkins University with the degree of Bachelor of Engineering in 1924, now engaged in research at that University upon high-voltage cable for the N.E.L.A. Similar research will be continued under the fellowship, especially with reference to the influence of various cable oils as used with impregnated paper cable. Results of his studies with Dr. Whitehead during the past four years have been published as A.I.E.E. papers.

Milton S. Plesset, a graduate of the University of Pittsburgh with the degrees of B.S. in 1929 and M.S. in 1930. He is now pursuing graduate study and research; his later work under the fellowship will be undertaken at Yale University and will deal with electron scattering in gases as a definite problem in interference. Thus he is seeking to determine the intensity of a scattered electron beam as a function of the angle of scattering.

Gerald D. Rahrer, graduating from Wabash College with the degree of A.B. in 1930. Mr. Rahrer is preparing to do research work upon electronic problems, particularly those dealing with thermions and the photo-electric effect. His research will be carried on at the University of Illinois.

Oliver C. Simpson, graduating from the University of Illinois, with the degree of B.S. in 1930. He is now engaged in graduate work at that institution. His later research, carried on under the foundation, will deal with atomic and molecular ray problems, such as the magnetic moments of atoms. This work will be a continuation of his present work at the University of Illinois.

David H. Sloan, a graduate of Washington State Normal in 1925, and of Washington State College with the degrees of B.S. and M.S. in 1928 and 1929 respectively. He is at present doing research engineering work on Thyratron tube development under Dr. Hull in the Research Laboratory of the General Electric Company at Schenectady. His research under the fellowship, to be carried on at the University of California, will deal with the conduction of electricity in gases at low pressure, especially in mercury vapor, with emphasis on its behavior in Thyratron tubes.

Jesse R. Watson, graduating from Pacific University with the degree of B.S. in 1930. Under the fellowship research will be carried on by Mr. Watson in problems relating to photo-electric effects of radiations of various kinds on various metals, and to electronic emissions and related subjects. His researches will be carried on at Stanford University where his work will lead toward a Ph.D. degree.

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

Amplifiers, Vacuum Tube

Automatic Neutralization of the Variable Grid Bias in a Direct Current Feed-Back Amplifier. Preston B. Carwile and F. A. Scott.
Rev. of Sci. Instr., Apr., 1930; v. 1, pp. 203-206.

Exact Compensation for the Effect of A and B Battery Changes When Using the Vacuum Tube as a D-C Amplifier. Raymond C. Dearle and Lorne A. Matheson.
Rev. of Sci. Instr., Apr., 1930; v. 1, pp. 215-226.

Arc Welding

Application of Arc Welding to Machine Design and Building Construction. A. M. Candy.
Am. Weld. Soc. Jour., Mar., 1930; v. 9, pp. 66-73.

Arc Welding of Structural Steel. J. J. Wallace.
Am. Weld. Soc. Jour., Mar., 1930; v. 9, pp. 61-66.

Carrier-Current Communication

Carrier Current Replaces Relay Pilot Wire. E. R. Stauffacher and F. B. Doolittle.
Elec. Wld., Mar. 22, 1930; v. 95, pp. 580-583.
(Equipment and methods used by the Southern California Edison Co.)

Circuit Breakers

Use of Oil in Arc Rupture. B. P. Baker and H. M. Wilcox.
A.I.E.E. Jour., Apr., 1930; v. 49, pp. 297-301.
(The relation between rupturing ability of circuit breakers and system stability problems. Abridgment.)

Corona

Coronal Discharge. H. A. Gould.
Franklin Inst. Jour., Apr., 1930; v. 209, pp. 485-501.

High-Voltage Corona in Air. Sigmund K. Waldorf.
A.I.E.E. Jour., Apr., 1930; v. 49, pp. 272-276.
(Abridgment.)

Daylight

Hygienic Effects of Ultraviolet Radiation in Daylight. Henry Phelps Gage.
Illum. Engng. Soc. Trans., Apr., 1930; v. 25, pp. 337-358.
(List of 29 bibliographic references, pp. 350-351.)

Sunlight—Natural and Synthetic. C. E. Greider and A. C. Downes.
Illum. Engng. Soc. Trans., Apr., 1930; v. 25, pp. 378-396.

Electric Arc

Extinction of a Long A-C. Arc. J. Slepian.
A.I.E.E. Jour., Apr., 1930; v. 49, pp. 310-314.
(Abridgment.)

Electric Cables

40,000-Volt Cables. G. K. Nowlan.
S. Af. I.E.E. Trans., Jan., 1930; v. 21, pp. 14-19.

Heat Flow and Permissible Loading of Grouped Single Conductor Cables. S. Whitehead and P. D. Morgan.
Wld. Power, Apr., 1930; v. 13, pp. 350-354.

Electric Conductors

Calculation of Induced Voltages in Metallic Conductors. Herbert Bristol Dwight.
A. I. E. E. Jour., Apr., 1930; v. 49, pp. 289-292.
(Abridgment.)

Electric Distribution

Cutting Distribution Costs. Thomas Sproule.
Elec. Wld., Mar. 15, 1930; v. 95, pp. 530-534.
(On costs of electric distribution.)

Electric Drive—Canal Locks

Electrical Operation of the World's Largest Lock on the Welland Canal. A. L. Mudge.
Elec. News & Engng., Mar. 15, 1930; v. 39, pp. 45-49.

Electric Furnaces

Electric Furnaces for Steel Melting. N. Ryland Davis and C. R. Burch.
Met.-Vick. Gaz., Mar., 1930; v. 12, pp. 67-70.

Electric Heating

Heat Pump—An Economical Method of Producing Low-Grade Heat from Electricity. T. G. N. Haldane.
Engrs. & Engng., Mar., 1930; v. 47, p. 64-72.
(A method for electric heating of buildings, pools, etc. From a paper read before the I.E.E.)

Thermal-Storage Heating Installation. P. Kempe.
Elec. Rev., Apr. 4, 1930; v. 106, pp. 625-627.
(A Sulzer Bros. electric boiler installation for hot-water heating of a building. The boiler operates at 6,600 volts, three-phase, 50 cycles.)

Electric Lamps, Arc-Incandescent

Simulating Sunlight; A New Era of Artificial Lighting. M. Luckiesh.
Illum. Engng. Soc. Trans., Apr., 1930; v. 25, pp. 397-405.
(On the health-producing properties of ultra-violet rays, and on the G-E sunlamp for producing ultra-violet rays artificially.)

Electric Measurements

Problem of Power Metering With Particular Reference to Errors in Connections. W. H. Gerrie.
Bul. of Hyd. Pr. Comm. of Ont., Mar., 1930; v. 17, pp. 80-93.

Electric Meters

Ultraviolet Light Meter. H. C. Rentschler.
Illum. Engng. Soc. Trans., Apr., 1930; v. 25, pp. 406-410.

Electric Power

Industrial Power. J. H. Lawrence and J. A. Freiday.
Engrs. Soc. of W. Pa. Proc., Dec., 1929; v. 45, pp. 403-425.
(The economics of industrial power plant design.)

Electric Transmission Lines

Impedance and Power Losses of Three-Phase Overhead Lines. P. D. Morgan and S. Whitehead.
I. E. E. Jour., Mar., 1930; v. 68, pp. 367-408.
(Technical Report F/T 37 of the British Electrical and Allied Industries Research Assoc. Methods of calculation. Bibliography, p. 408.)

Electrical Machinery

Generalized Theory of Electrical Machinery. Gabriel Kron.
A. I. E. E. Jour., Apr., 1930; v. 49, pp. 302-305.
(Abridgment.)

Electrical Machinery—Temperature

Ventilation of Revolving Field Salient-Pole Alternators. Carl J. Fechheimer.
A. I. E. E. Jour., Apr., 1930; v. 49, pp. 263-267.
(Abridgment.)

Electricity—Applications—Motion Pictures

Modern Incandescent Lighting in Kinema Studios. W. A. Villiers.
Illum. Engr., Apr., 1930; v. 23, pp. 87-91.

Electrons

Integraph Solutions of Electron Orbits in the Barkhausen-Kurz Effect. Francis W. Sears.
Franklin Inst. Jour., Apr., 1930; v. 209, pp. 459-472.

Hydroelectric Plants

Ice as Affecting Power Plants; Final Report of Committee of Power Division.
A. S. C. E. Proc., Apr., 1930; v. 56, pp. 743-759.
(Bibliography, pp. 754-759.)

Insulation—Testing

Testing Insulation Without Destroying It. Robert Sparks.
Elec. Jour., Apr., 1930; v. 27, pp. 229-230, 237.
(The Schering bridge method.)

Lightning

Lightning Investigation on 132-Kv. System of the Ohio Power Company. Philip Sporn and W. L. Lloyd, Jr.
A. I. E. E. Jour., Apr., 1930; v. 49, pp. 259-262.
(Abridgment.)

Measuring Instruments

The Klydonograph.
Franklin Inst. Jour., Apr., 1930; v. 209, pp. 533-538.
(Describes the device and its uses.)

Oscillographs

Cathode Ray Oscillograph With Norinder Relay; Its Design and Application. O. Ackermann.
A. I. E. E. Jour., Apr., 1930; v. 49, pp. 285-289.
(Abridgment.)

Phototelegraphy

System of Electrical Transmission of Pictures. Yasujiro Niwa.
Elec. Commun., Apr., 1930; v. 8, pp. 283-295.
(A paper presented before the World Engineering Congress, Tokyo.)

Potentiometers

Alternating-Current Potentiometers and Their Applications. C. V. Drysdale.
I. E. E. Jour., Mar., 1930; v. 68, pp. 339-366.
(The evolution of the potentiometer, followed by descriptions of the Drysdale-Tinsley, Larsen, Gall, Pedersen, Campbell, and other types. Also considers theory, accuracy and applications. Bibliography, p. 360.)

Protective Apparatus

Can Petersen Arcing Ground Suppressors Cause Deleterious Over-Voltages? J. Biermanns.
AEG Progress, Apr., 1930; v. 6, pp. 101-105.

Development of Protective Equipment. W. Wilson.
Wld. Power, Apr., 1930; v. 13, pp. 342-349.
(Discusses various protective schemes in use today.)

Fault Ground Bus, Its Use and Design in Brunot Island Switch House of Duquesne Light Company. R. M. Stanley and F. C. Hornibrook.
A. I. E. E. Jour., Apr., 1930; v. 49, pp. 306-310.
(Abridgment.)

Radio Engineering—Crystals

Piezo-Electric Resonator in High-Frequency Oscillation Circuits. Yasusi Watanabe.
Inst. Radio Engrs. Proc., Apr., 1930; v. 18, pp. 695-717.

Radio Engineering—Shielding

Aircraft Engine Ignition Shielding.
Franklin Inst. Jour., Apr., 1930; v. 209, pp. 545-548.
(A note from the U. S. Bur. of Stds.)

Engine-Ignition Shielding for Radio Reception in Aircraft H. Diamond and F. G. Gardner.
Bur. Stds. Jour. Res., Mar., 1930; v. 4, pp. 415–424 (RP No. 158).

Radio Engineering—Transformers

Design of Small Transformers and Choke Coils for Radio Work. A. N. Chittleborough.
Elec. Engr. of Aust. & N. Z., Feb. 15, 1930; v. 6, pp. 409-411.

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Transmission Characteristics of a Short-Wave Telephone Circuit. R. K. Potter.
Inst. Radio Engrs. Proc., Apr., 1930; v. 18, pp. 581-648

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Ultra Short Radio Waves. W. H. Moore.
Franklin Inst. Jour., Apr., 1930; v. 209, pp. 473-483.
(Includes a list of 12 bibliographic references.)

Radio Engineering—Wave Propagation

Summary of Progress in the Study of Radio Wave Propagation Phenomena. G. W. Kenrick and G. W. Pickard.
Inst. Radio Engrs. Proc., Apr., 1930; v. 18, pp. 649-668.
(Includes a bibliography of 100 entries, pp. 664-668.)

Radio Receivers

Considerations in Superheterodyne Design. E. G. Watts, Jr.
Inst. Radio Engrs. Proc., Apr., 1930; v. 18, pp. 690-694.

Radio Stations

Transoceanic Telephone Service Short-Wave Equipment; Technical Features of the New Short-Wave Radio Stations of the Bell System. A. A. Oswald.
A. I. E. E. Jour., Apr., 1930; v. 49, pp. 267-272.
(Abridgment.)

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Design and Results of a 600 Lb. Per Sq. In. Boiler Installation. William Nithsdale.
Engng., Mar. 28, 1930; v. 129, pp. 406-408.
(Abridged from a paper read before the I. M. E. Discussion, pp. 416-418. Appears also in *Engineer* of the same date, pp. 356-357. This latter is a serial.)

Switches and Switchgear—Testing

The Camera as an Aid to Electrical and Mechanical Testing. L. B. Woodworth.
S. Af. I. E. E. Trans., Jan., 1930; v. 21, pp. 19-23.
(On the use of the motion picture camera for recording the performance of switchgear under fault conditions.)

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Reproduction and Amplification in Television Receivers. Fritz Schröter.
Television (Brit.), Apr., 1930; v. 3, pp. 71-76.
(Serial.)

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Accuracy of Current Transformers. J. B. Gibbs.
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Transformers—Temperatures and Cooling

Loading Transformers By Temperature. V. M. Montsinger.
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(Abridgment.)

Turbine-Generators

Mechanical Degree of Safety in Large Turbo-Generators. H. Rickli.
Engng., Mar. 28, 1930; v. 129, pp. 421-423.
(Abridged from a paper read before the World Power Conference, Tokyo, Japan.)

Ultra-Violet Rays

Recent Developments of Window Materials and Fabrics for Transmitting Ultraviolet Radiation. W. W. Coblentz.
Illum. Engng. Soc. Trans., Apr., 1930; v. 25, pp. 359-377.
(List of 21 bibliographic references, p. 369.)

Voltage Regulation

Voltage Control of Large Alternators. H. W. Taylor.
I. E. E. Jour., Mar., 1930; v. 68, pp. 317-338.
(Discusses stability and response in alternator and exciter.)

Welding

Four Years' Experience With Structural Welding. A. L. Wilson.
Am. Weld. Soc. Jour., Mar., 1930; v. 9, pp. 38-53.

Welding Stainless Steel and Monel Metal. M. E. Olsen.
Am. Weld. Soc. Jour., Mar., 1930; v. 9, pp. 25-32.

Welds—Testing

Electrically Welded Structure Under Dynamic Stress. Morris Stone and J. G. Ritter.
Am. Weld. Soc. Jour., Mar., 1930; v. 9, pp. 15-24.

Investigation of Welded Connections Between Beams and Columns. Eugene H. Uhler and Cyril D. Jensen.
Am. Weld. Soc. Jour., Apr., 1930; v. 9, pp. 61-87.

Physical Properties of Electrically Welded Steel Tubing. H. L. Whittemore and others.
Bur. Stds. Jour. Res., Apr., 1930; v. 4, pp. 475-500 (RP No. 161).

Strength Investigations on Welded Beam Connections. Charles H. Jennings and A. A. Jakkula.
Am. Weld. Soc. Jour., Apr., 1930; v. 9, pp. 22-41.

Theory of Stresses in Welds. Leon C. Bibber.
Am. Weld. Soc. Jour., Apr., 1930; v. 9, pp. 104-137.

NEW BOOKS

(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.)

Alternating Currents for Technical Students. Calvin C. Bishop. 317 pp., 1930, N. Y., D. Van Nostrand Co., Inc. $2.00.

(A graphic explanation, with the aid of simple mathematics, of the fundamental principles of alternating-current theory, circuits, and apparatus. "Intended for technical and vocational students, engineering students and others who are familiar with direct-current theory but find themselves called upon to become familiar with alternating-current theory and apparatus." The thirteen chapters are devoted to the topics: "Alternating Currents," "Alternators," "Inductance," "Capacity," "Series Circuits," "Parallel Circuits," "Vectors," "Transformers," "Asynchronous Motors," "Synchronous Motors and Rotary Converters," "Other Alternating Current Apparatus," "Practical Tests and Measurements," and "Trigonometry Useful in Solving Vector Problems." Most of the chapters are supplemented by lists of problems intended to be solved by the student.)

Atoms, Molecules and Quanta. Arthur E. Ruard and Harold C. Urey. 790 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $7.00.

Bonbright Survey of Electric Power and Light Companies of the United States. Ed. 6. G. F. Wittig (Editor). 194 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $10.00.

Electromagnetic Problems in Electrical Engineering. B. Hague. 359 pp., 1929, N. Y., Oxford University Press. $10.00.

(The subtitle classifies this as "an elementary treatise on the application of the principles of electromagnetism to the theory of the magnetic field and of the mechanical forces in electrical machinery and apparatus." The volume is addressed to two main classes of reader, and is intended to serve two principal purposes. With this in view it is divided into two parts. Part I is for the use of advanced students and others who require an elementary discussion of the principles of electromagnetism, so far as those principles have a bearing upon the physical theory of electrical machinery and apparatus. Part II is for the use of engineers, and applies the principles laid down in Part I to the solution of a number of important electrotechnical problems. The reader is assumed to have a good general knowledge of electricity and magnetism and of electrical engineering, a fair knowledge of differential and integral calculus, including partial differentiation and multiple integrals, and an acquaintance with vector analysis and Fourier's series.)

Electroplating with Chromium, Copper and Nickel. Benjamin Freeman and Frederick G. Hoppe. 212 pp., 1930, N. Y., Prentice-Hall. $5.00.

High Voltage Cables. L. Emanueli. 107 pp., 1930, N. Y., John Wiley & Sons, Inc. $2.50.

(In an introduction to this volume, Mr. Wm. A. Del Mar has this to say: "As a rule, books by European cable experts have limited value to Americans because of the great differences in practice on the two continents. Here, however, we have a work which deals with principles rather than details of practice and which therefore has no geographical limits to its usefulness. . . In referring to principles, I refer to engineering rather than physics, as the book does not attempt to discuss the various modern physical theories of dielectric behavior. Its treatment of what has been called the 'XIX Century' physics of cable making, such as thermal, capillary and pressure effects, would alone make the book valuable to cable engineers." Mr. Emanueli's book is made up of five lectures entitled: Introduction, Impregnating Compound, The Electrostatic Field, The Dielectric of a Cable Considered from the Point of View of Its Impregnation, and Mechanical and Electrical Properties of the Finished Cable.)

Industrial Electricity and Wiring. James A. Moyer and John F. Wostrel. 469 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $2.75.

Materials Handling Equipment. Edward J. Tournier. 371 pp., 1929, N. Y., McGraw-Hill Book Co., Inc. $4.00.

Metallurgy of White Metal Scrap and Residues. Edmund R. Thews. 383 pp., 1930, N. Y., D. Van Nostrand Co. $5.50.

Navigation of Aircraft. Logan C. Ramsey. 237 pp., 1929, N. Y., Ronald Press Co. $4.50.

Practical Radio Construction and Repairing. Ed. 2. James A. Moyer and John F. Wostrel. 353 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $2.50.

Principles of Electrical Engineering. Ed. 2. William H. Timbie and Vannevar Bush. 595 pp., 1930, N. Y., John Wiley & Sons. $4.50.

Principles of Electroplating and Electroforming. Ed. 2. William Blum and George G. Hogaboom. 424 pp., 1930, N. Y., McGraw Hill Book Co., Inc. $4.50.

Starkstromtechnik; Taschenbuch für Elektrotechniker. Vol. 1. Ed. 7, rev. E. v. Rziha and J. Seidener (Editors). 1039 pp., 1930, Berlin, Wilhelm Ernst & Sohn. 34 R.M.

(This is the seventh edition of a well-known and popular German handbook covering, in two volumes, the field of heavy-current engineering. In the preparation of this revised and enlarged edition the editors have had the collaboration of many German specialists, and have been enabled to present a comprehensive survey sufficient for the ordinary needs of the electrical engineer. Vol. 1 consists of twelve sections devoted to the following subjects: review of mathematics; physical principles underlying the practice of electrical engineering; electrical measurements and measuring instruments; rotating machinery and transformers; examples of actual machines; rectifiers; storage batteries; starters and regulators; switchgear; wiring and installation work; lighting; and the applications of electric heat, including electrometallurgy. The second volume will deal with the power plant, transmission networks, and the various applications of electric power to industry, railways, ships, and agriculture.)

Storage Batteries; a General Treatise on the Physics and Chemistry of Secondary Batteries and Their Engineering Applications. Ed. 2, rewritten. George Wood Vinal 427 pp., 1930, N. Y., John Wiley & Sons, Inc. $5.00.

(The extensive use of storage batteries for automobile starting and lighting, truck and tractor propulsion, train lighting, railway signalling, telephone work, isolated plant service, and in a host of other applications, creates a need for a modern textbook on battery construction and care. To fill that need we are now offered this revised edition of a treatise on the theory, manufacture, application, and maintenance of storage batteries in general. The various topics covered include materials and methods of manufacture, electrolytes, theory of battery reactions, capacity, operation, resistance, efficiency, testing, and uses. Bibliographic footnotes and occasional short lists of references add to the value of the work. An adequate index is a useful adjunct.)

Worked Examples in Electrical Technology. F. Peasgood and H. J. Boyland. 219 pp., 1929, N. Y., Oxford University Press. $5.00.

(A collection of graded problems for students of electrical engineering. The problems are divided into three sections devoted, respectively, to The Direct Current Circuit, The Magnetic Circuit, and the Alternating Current Circuit. Each section is subdivided into a number of groups of problems each on some specific topic pertaining to that section. Each problem is stated and its solution presented. At the ends of the three sections, under the heading "Exercises," are other problems for which no solutions are included.)

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VOL. 33, NO. 8 AUGUST, 1930

Geo. W. Kelham, Architect

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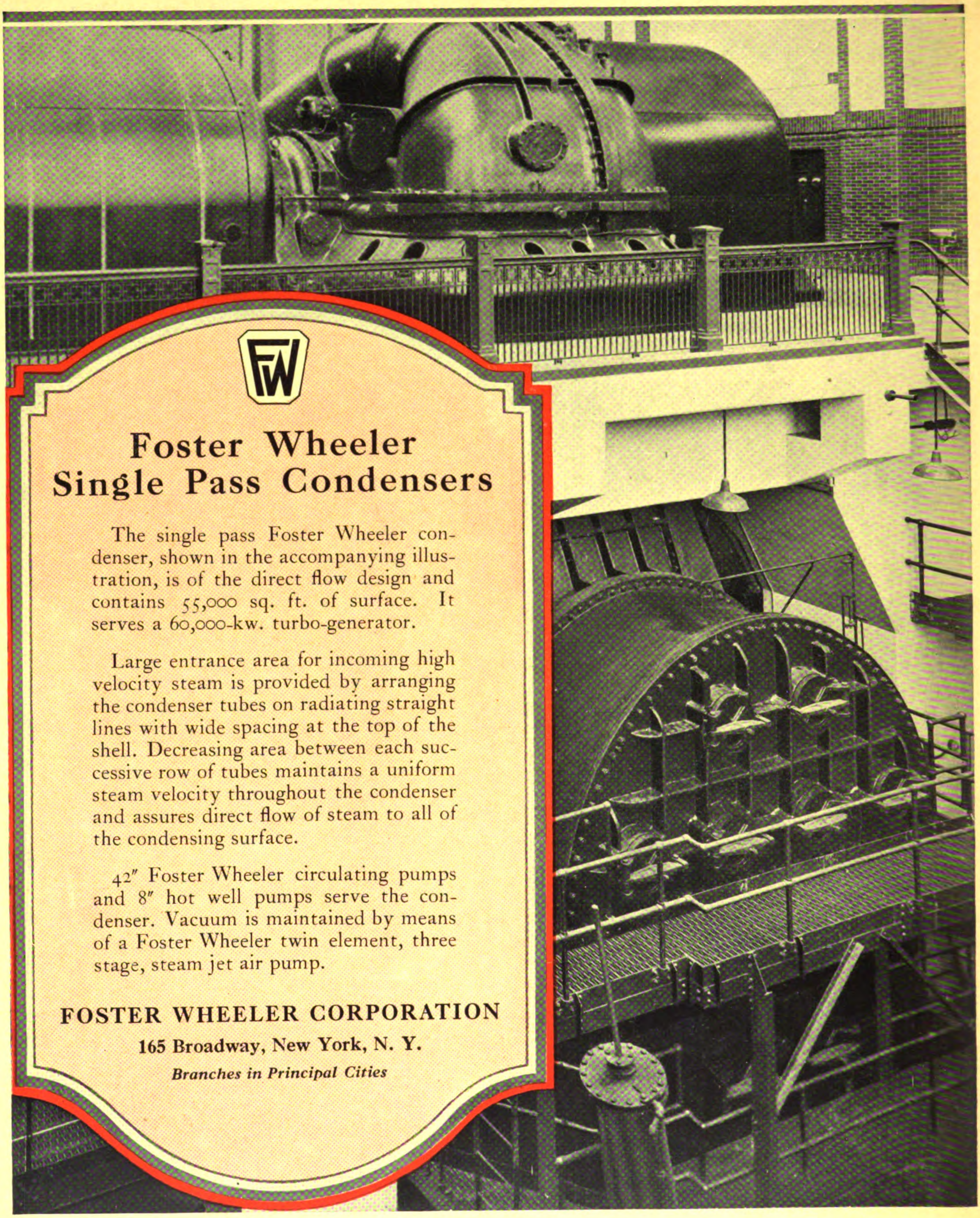

FW

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The single pass Foster Wheeler condenser, shown in the accompanying illustration, is of the direct flow design and contains 55,000 sq. ft. of surface. It serves a 60,000-kw. turbo-generator.

Large entrance area for incoming high velocity steam is provided by arranging the condenser tubes on radiating straight lines with wide spacing at the top of the shell. Decreasing area between each successive row of tubes maintains a uniform steam velocity throughout the condenser and assures direct flow of steam to all of the condensing surface.

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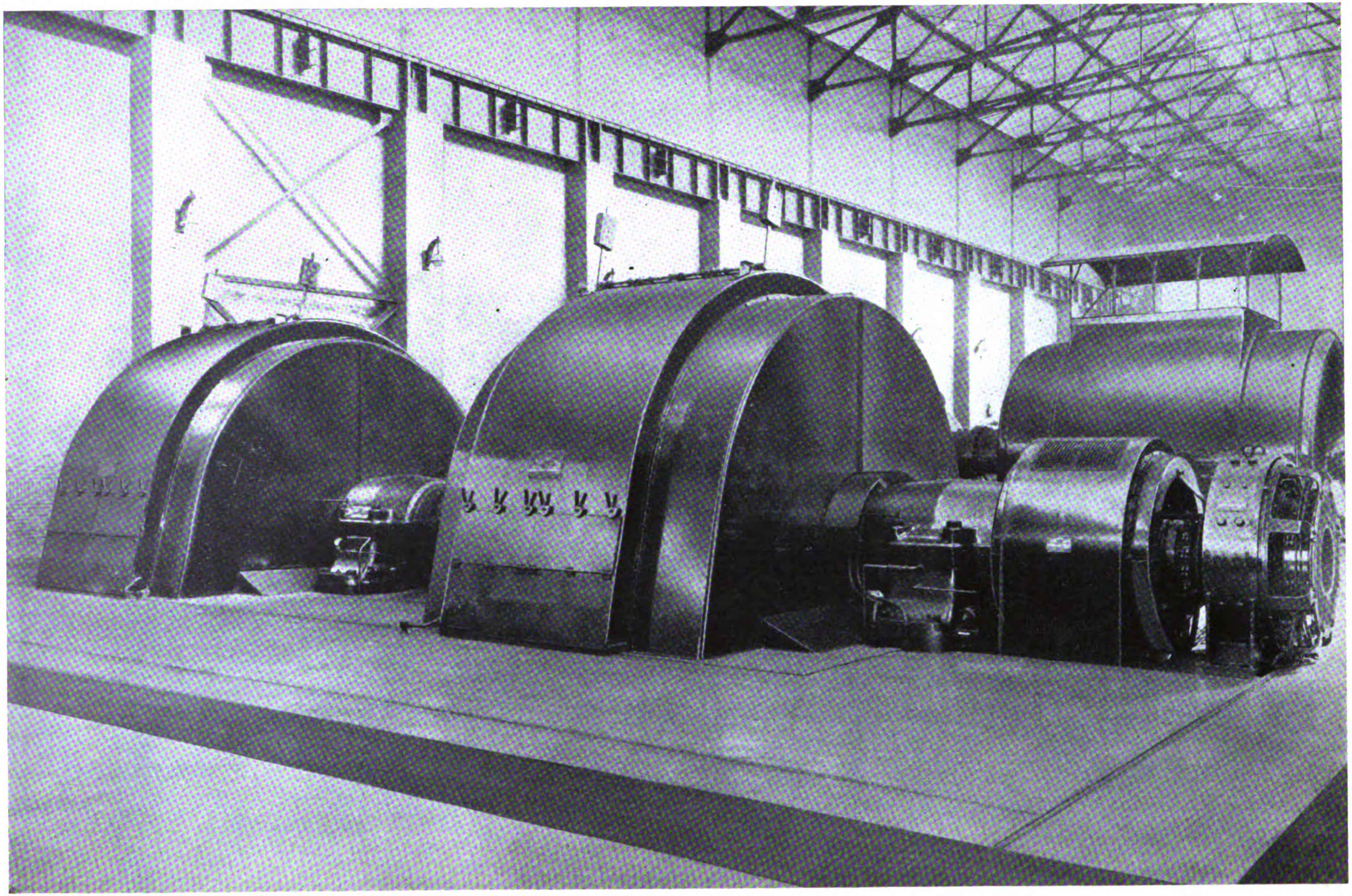

FOR SERVICE AND STABILITY

A frequency converter consisting of a 3-phase 60-cycle 13,500-volt 48,000-hp. synchronous motor and a 3-phase 25-cycle 6750-volt 35,000-kw. synchronous generator with their auxiliary machines in the Acme Station of the Toledo Edison Company *(See p. 476)*

GENERAL ELECTRIC

REVIEW

Vol. 33 August, 1930 No. 8

THE ARID ZONE

In the musical language of the early Spanish explorers the great Arid Zone of the mysterious Southwest became ARIZONA. Only a few years ago the word "unexplored" was written large across the map of this immense area—a territory containing so many natural wonders that no pen has yet rendered a true description of them, or brush yet succeeded in painting more than a fleeting picture of their ever-changing enchantments.

Until a few years ago all the mysterious glories and wonders of this great "never, never land," with its parched and dusty deserts under a blazing sun, and under the eternal blue of her cloudless skies, were unknown.

The stunted growth of her desert vegetation, her gaunt giant cacti, her Gila monsters and her rattlesnakes, together with her mighty untamed rivers and enchanted mountains all seemed too forbidding for civilization.

Even the priceless glories of her nights had remained unwritten and unsung—nights under an azure sky studded with a multitude of stars shining as stars can shine only over a desert, and turning her nocturnal hours into a symphony of the heavens and her landscape into an enchanted and mysterious wonderland.

Only a few years ago Arizona was like a jewel in the ground—an undiscovered glory. For years after her discovery she was still like an uncut jewel—her beauty and her wealth were unrevealed.

Arizona was known to but a mere handful of Indians until the white man came with his unquenchable thirst for victory over the unexplored, his daring, and indomitable pioneer spirit. And until in the white man—

> ". . . A Voice, as bad as Conscience, rang interminable
> changes
> On one everlasting Whisper day and night repeated—So;
> "'Something hidden. Go and find it. Go and look behind
> the Ranges—
> "Something lost behind the Ranges. Lost and waiting
> for you. Go!'"

* * * * *

Lovers of adventure and discovery, and of courage and romance, should read the story of the American army on frontier duty some fifty years ago in this land of many mysteries and untold hardships.

* * * * *

About twenty years ago we first visited Arizona and fell under the spell of her charm. About three months ago we stood on top of a tall building in Phoenix and saw the country that but a brief two decades earlier had been a parched and barren desert now blooming like the Garden of Eden. We could not help repeating—"Saul he went to look for donkeys, and by God he found a Kingdom."

The white man had dammed the great Salt River; and this and many similar undertakings had brought hundreds of thousands of acres of erstwhile desert under cultivation.

The growth and grandeur of Arizona are too long a story to tell here, but since the white man came "and bridged and roaded and ruled the land" he has transformed a wilderness into an empire. Arizona today, although the youngest Commonwealth that finds shelter under the protecting roof of that great edifice known as the Federal Government, is among the most progressive of her States.

Arizona advanced by leaps and bounds, but like the rest of the world suffered a severe shock and setback during the post-war depression in 1921. How this youngest Commonwealth faced her troubles and mastered them is an instructive story. A state-wide Industrial Congress was formed and disaster was turned into an industrial triumph.

In Phoenix, a few months ago, we had the pleasure of visiting Mr. P. G. Spilsbury, the President of the Arizona Industrial Congress. We were so inspired by his story that we asked him to write it for the REVIEW. Although this story is of a somewhat unusual character for our columns we feel that it contains the great and instructive lesson of what coöperation and coördination in industry can do. It is of special interest at the present time when business is suffering from the blues.

* * * * *

We have the feeling that in our present industrial system there is an Arid Zone. In times of depression we too often discharge the least efficient workers—those who obviously are the least capable of looking after themselves in good, or in hard, times. Also we cut out the dead wood, an always sad, but sometimes inevitable process. It should ever be remembered that the wood that is dead today may have yesterday borne the fruit that will ripen into future prosperity.

Our industries are marvelously vigorous and wonderfully young; and we believe in the majority of cases guided by great-hearted executives.

In the future some plan must be developed to smooth out, more or less, the peaks of prosperity and the valleys of depression—to iron them out into a gradually ascending curve.

We hail with joy the Swope plan for stabilizing employment and the rules he has laid down to be followed in times when business is increasing and when business begins to fall off. This, and other similar plans, should in the future prevent much suffering, and pave the way for bolder plans.

Stabilization of employment is much easier in some industries than in others. In some, at present, more than a partial stabilization cannot be looked for.

The idealist may shout—

> "I have found it, the road to the rest ye seek:
> "The strong shall wait for the weary, the hale shall halt
> for the weak:"

But the practical executive must obey certain laws of economics if he is to court anything but disaster. The laws of economics have been sometimes as harsh as the laws of Nature. Nature ruthlessly weeds out and destroys the inefficient and unfit. But Nature has yet another law—living things perpetually strive to gain a higher place in the great scheme of evolution. Industry is evolving, and so man with a greater wisdom, an increased intelligence and more humanity is trying to evolve schemes to help the less fit in times of trouble so that they may contribute their small, but necessary, quota to the whole in times of prosperity.

The weak and inefficient must make some contribution for the rainy days during the sunshine of prosperity. A wilful improvidence should not share the hard-earned wages of thrift.

> "You can lighten the curse of Adam when you've lifted the curse of Eve—
> But till we are built like the angels—with hammer, chisel and pen,
> We will work for ourselves and a woman, forever and ever amen."

Thus spoke the voice of individualism in the past when each worked and fought for himself and the devil took the hindmost. But now, and in the future, each, the weak and the strong alike, must make some sacrifice in times of prosperity to avoid suffering in times of adversity.

Industrial conditions have improved so immeasurably in the last brief century that we have every right to look for still better conditions in the future. "Fear is the worst enemy of mankind" and the constant fear of unemployment among certain classes leads to the inefficient becoming yet more inefficient.

We envy a Michael Angelo who could see an angel in a block of stone and himself have the genius and skill to produce that angel.

Idealists may wish for, and picture, better industrial conditions with less suffering and hardships, but we know that the production of these better conditions must be left to the genius of hard-headed and big-hearted executives, if they are to be practical, lasting, and economically sound.

In the past we have had fears lest there was an inherent and inevitable conflict between the laws of Nature and economics on the one hand, and humanity on the other; but now, taught by the history of the immediate past in general and the trend of America's industrial developments in particular, we have an increasing confidence and faith that man's wisdom and intelligence, those twin children of human evolution, can and will gradually prove that—

> "The quality of mercy is not strain'd."
>
> "It blesseth him that gives, and him that takes:"
> "'Tis mightiest in the mightiest; it becomes
> The throned monarch better than his crown;"

Industrial wealth is the crowned monarch of the present age; and industry seems to have learned the golden lesson that well-paid and reasonably contented workers are the best business assets in the world. Big wages pay if they lead to a greater production.

"They are as sick that surfeit with too much; as they that starve with nothing."

Our modern civilization has become a most complex industrial institution and it can be considered successful only in such measure as it leads to the more equitable distribution of wealth. We look to able management aided by Science, Research, and Technical Developments, gradually to formulate plans to eliminate that dreaded word "Unemployment" from the charts of Industry and thus convert that Arid Zone in our present system into a fruitful valley.

J. R. H.

Arizona Industrial Congress

By **P. G. SPILSBURY** and **H. E. O. WHITMAN**
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> *On a recent visit to Arizona we met Mr. Spilsbury and were so impressed with the wonderful work of the Arizona Industrial Congress that we asked him to write an article for our columns. We believe all business men as well as engineers will be interested in his contribution.*—EDITOR

ONE of the most significant developments growing out of the past winter's business trends has been the attention given to the desirability of some plan for coördination of industry in this country—some correlation of activity whereby industrial balance may be maintained and prosperity stabilized. Industrial coördination was stressed in the business conferences called last fall by President Hoover, and it is probably safe to say the subject has been mentioned more often in the past six months than at any time before.

Recessions always remind us that business and industry, after all, are only man-made contrivances to satisfy the wants of people. The specialization of the Industrial Age gives our economic structure strength; but also a certain weakness. Since all industries must depend on public demand for goods or services, they really depend on each other, for the total of the earning and purchasing power they afford *people* must provide the wherewithal with which that public demand may be kept up.

P. G. SPILSBURY

The development of vast specialized industries, in other words, has intensified the interdependence of industry, and therefore of people. No longer do we grow our own food and make our own clothes; nor could we be satisfied with such simple things as food and clothes. We produce or do one thing—to sell to others. If everybody is able to make money with which to buy, we have prosperity. If a large number of people are unable to make money, the rest are likely to suffer, as just so much public demand is stopped.

Business is only the machinery we have set up for the exchange of goods or services. Industry is only the processes by which commodities are produced or made useful. In its true sense the word covers all forms of productive endeavor. Farming, mining, transportation, construction, are as truly industries as manufacturing. Each is made up of people producing or providing something needed by people engaged in all the other industries. The problem, economists tell us, is so to coördinate their activities that each industry will function more evenly in balance with the others. If we do this, their very interdependence can be made a source of strength, for the stability of one will help to stabilize the others, and their stability will help to maintain the stability of the first, because income and purchasing power will be stabilized.

It is not the purpose of this article to presume to suggest how this might be done, nor to continue a trite discussion of its reasons. But while the subject is engaging the sober thought of many business leaders, it may be interesting to note that practical coördination of industry actually has been accomplished in the state of Arizona, and to hear how it was brought about.

The method is an "Arizona Plan" which Herbert Hoover, when Secretary of Commerce, termed a "distinct contribution to coöperative effort in the solution of our economic problems." The agency is a statewide organization of industries called the Arizona Industrial Congress. Its story demonstrates that coördination of industry—coöperation *between* industries as well as *in* industry—is both feasible and valuable, because the plan has eight years of successful operation behind it to prove its principles are sound.

Virtually the same plan, moreover, has been in use in the New England States for the past several years, through the New England Council. And at the present time the "Arizona Plan" is receiving the close study of the "Committee of Twenty-five" of the New York Statewide Economic Congress, headed by Merwin K. Hart of Utica, in developing plans for a very similar organization in New York State—to whose attention it was called by President Hoover last fall.

Just as the recent discussions of the need of some form of industrial coördination received impetus from disturbed economic conditions, so the "Arizona Plan" had its inception in the darker days of the post-war depression, in 1921. Or it might be more proper to say that the organization had its inception then, for the "plan" itself developed gradually, out of experience, so that no theory was incorporated in it until it had been tried.

The 1921 slump hit Arizona particularly hard. It was a young state, large in area but small in population, and only well started in its development. Its great copper mines were shut down; its farmers faced ruin because their long-staple cotton and other crops could not be sold for even a reasonable part of their cost of production; its stockmen, over-extended on credit and also hurt by drought, were without markets for their cattle, sheep, and wool. Business, growing too fast, was staggering under the sudden change from boom to depression, and taxes alone were holding the high level of the war years.

As frequently happens in such times, there was a tendency for everybody to blame everyone else for their troubles. This was the case one day in the fall of 1921 when a little group of men chanced to lunch together in a Phoenix club. It happened that one was a farmer, one a stockman, one a business man, one a lawyer, one a consulting mining engineer. The talk, as usual, concerned the deplorable condition of affairs in general. The farmer, the stockman, the business man, the lawyer, carried on a lively argument as to causes and effects—an argument in which complaints revealed a striking variance of opinion.

The mining engineer did not take part in the discussion, because it had given him an idea. Presently he said, "Instead of sitting here talking about our problems, why not try to do something? The real trouble is that we're so wrapped up in our own affairs we're only trying to pass the buck by blaming everything and everybody else. You've just admitted that you, or the lines of business you represent, are dependent on each other to a large extent. Then why can't we call all our industries together, talk things over just as we are doing, and see if we can't find a solution for our difficulties by trying to help each other? If we understood each other better it seems to me we could find a basis for working together to clear things up."

The idea appealed. The little group of five began to talk it over with other men; then with organizations. Everyone agreed that if all interests could really get together they could eliminate a lot of misunderstandings and working at cross-purposes, and accomplish some constructive good. Presently a large group of representative citizens sponsored a proposal that all Arizona join in a State Industrial Conference. Practically every organization in the state got behind it, and when the conference was held in December there were in attendance three hundred leading figures in the state's industrial and business life.

There was a striking lack of "bull" in that first Industrial Conference. Things were too serious for that. Man after man—men who were known for leadership, success, and ability—got up and stated frankly and flatly just where his particular industry or section stood; what it needed, what it was trying to do, what others could do to help it, what would certainly happen if improvement did not come. Steadily and surely during those two days they built up a composite picture of Arizona as a single whole economic unit, made up of separate but interlocking units which were their own businesses or industries.

Once that picture of an economic whole was presented, the next step was plain. Obviously, anything which helped one industry or one part of the state would help all indirectly. Equally obviously, there were many things that they could do to help each other if they tried, and by doing them they eventually would help themselves. What was needed first was some central coördinating influence to make a practical form of coöperation possible.

The answer was the formation of the Arizona Industrial Congress. A constitution and by-laws were drafted on the spot, and directors elected. P. G. Spilsbury, the mining engineer who had conceived the idea and taken a leading part in carrying it out, was chosen the organization's president and active operating head.

Spilsbury, like many engineers, was a good deal of an economist. A native of New York and a graduate of Lehigh, his profession had taken him all through the Southwest, Mexico and Central America. He had had business experience in New York City. Management of a large concession in Costa Rica had given him a very practical insight into problems of new development and administration. With him on the governing board, which has always been an exceedingly active one, were a score of the state's outstanding men. Thus the organization had at its disposal, and has had ever since, some of the keenest business heads in Arizona.

The men who founded the Industrial Congress envisioned it not as an extensive—and expensive—new organizational machine, but rather as a clearing-house. Virtually every industry in the state already had an organization of its own. Most communities likewise had their own organizations—chambers of commerce, business men's associations, service clubs, women's clubs. Through these organizations the Industrial Congress could reach all interests and all sections; its function primarily was to provide them a point of contact for better understanding of each other's problems, for exchanging coöperation in trying to solve them, and for coördinating their efforts toward a common end.

In effecting the central organization, therefore, these other organizations, or the industries they represented, made up the basic membership. All economic interests of the state were included in six major divisions of which the Congress was formed. These divisions were Agriculture; Business and Finance, including manufacturing, wholesale and retail business lines and banks; Livestock; Mining; Professions, including doctors, lawyers, engineers, teachers and similar organized groups; and Public Utilities, including railroads, light and gas companies, power companies and telephone and telegraph companies.

To assure that no single interest could dominate the whole, each of these divisions was given equal representation on the board of directors, and each agreed to subscribe equally with the others to the operating budget. Three directors from each division, elected by the organizations composing that division, made up the governing board, and five directors at large were then chosen by the board itself to give representation to important sections or industries which might not be represented already.

Carrying out the clearing-house idea, it further was provided that the presidents of the active state organizations included in the various divisions should serve automatically as directors from those divisions, during their terms of office. In this way the clearing-house was made more flexibly responsive to the work of its member bodies. Organizations thus automatically represented include the state farm bureau, cattle growers' and wool growers' association, bankers' association, newspaper association, state mining congress, state medical, bar, and educational associations, state utilities association, etc.

Arizona's economic problem, as the Industrial Congress analyzed it, fell naturally into two parts. The first was to restore some degree of prosperity and stability to existing industry and business, for the state's prosperity and growth must depend on the earning power of its people. The second was to increase and stabilize new development—agricultural, industrial, recreational, any type which would make potential resources productive,—so that existing industry and business could expand and new industries and business have a sound opening.

The Industrial Conference itself had cleared the way to tackling these problems by making it plain that every industry in the state had a very direct interest in the welfare of other industries. Although the mining industry was dependent primarily on world copper markets, it had a real "stake" in the success and growth of farming, manufacturing and business, for mining paid half of Arizona's taxes, and this portion would be reduced only as other economic groups advanced in taxable wealth. Farmers, stockmen, business men, had a real "stake" in mining, for the mining industry afforded the largest single purchasing power in the state, and approximately one-fourth of Arizona's population lived in mining sections. Business men naturally were interested in the welfare of farmers and stockmen and every other type of occupation. So were railroads. Every economic group in the state was shown it had a "selfish" interest in every other group, and therefore a motive for coöperating with them.

Perhaps the most interesting feature of the coöperative theory developed by the Congress was that it was based solely on *profits*. Arizona's material well-being, it boldly proclaimed, depended on the profits made by its people—steady employment and a fair wage for its workers, fair returns for its producers, fair returns for its invested capital. Because these *profits*, no matter what form they took, made up earning and purchasing power, every individual citizen as well as every individual industry or branch of business had a financial interest in his neighbors. His profits must depend on theirs, no matter what he did.

This, remember, was at the end of 1921; the Industrial Congress began to function as an organization on January 1, 1922. Effects of the depression had not abated; some relief was in sight, for mines were reopening as national and world conditions passed the worst, but Arizona's recovery threatened to be a slow, hard pull. So the Industrial Congress lost no time in going into action to do whatever could be done most quickly to help Arizona people, or any group of them. A well-rounded, long-period program would develop of itself as the work went on, but the immediate need was to get started.

The first step was to launch an "Use Arizona Products" movement. It was the most simple way to help producers to market their products. With it was launched a "Trade at Home" movement, to help merchants and business men get what business was available. Farm bureaus, chambers of commerce, women's clubs, got behind them actively. So did industries, for they could be shown where all this was to their interest. Through enthusiastic support of the newspapers, public interest was aroused.

Such movements, undoubtedly, have been attempted many times, in many places. Even Great Britain is carrying on just such an effort on a national scale: "Buy British and Be Proud Of It." In Arizona the campaigns succeeded because the Industrial Congress established in them the idea of reciprocity for profit, and also because it went farther and set about showing producers and business firms what they must do to get the business. It told them quite frankly that business must always be competitive; that they must offer standard quality and standard service at a standard price. Only when these conditions were equal with competitive products and competitive business could they expect to receive preference on any constructive basis even in their own market.

Since Arizona's farming industry, comparatively new and less well-entrenched than others, had been hardest hit by the slump, and had the greatest possibilities for rapid development, many of the Industrial Congress' efforts were turned to its assistance. The Farm Bureau recognized that coöperative marketing offered the most effective remedy for the farm problem, but farmers were in no shape to finance organizations. Coöperation of industry came to the rescue, and the Industrial Congress obtained the financial backing of mining companies to form the needed commodity-marketing bodies. Several new organizations were set up and previously-started cotton and citrus associations were strengthened. Today they play a prominent part in satisfactorily marketing the state's leading crops.

Marketing Arizona products fell naturally into several classifications of activity. The state's copper production must go into world markets. So must its wool and cotton. So, to a large extent, must its cattle and lambs. In such cases the Industrial Congress could help best by joining with other state and national agencies in endeavoring to stimulate increased consumption of these commodities in a general way. Effective distribution machinery was already available. In the case of cotton the central organization did valiant service in backing coöperative marketing; it aided live stock associations in numerous financial, rate and marketing adjustments; it coöperated with copper interests in developing new uses for the "everlasting metal" and in advertising its qualities.

Next there was a group of products which were intended largely for consumption outside the state, but which could be more widely used in its home markets, and which in many cases needed better organized machinery to attain outside distribution. These products included citrus fruits, hay, lettuce, cantaloupes. The Industrial Congress helped the citrus organization build up an Arizona market for a considerable part of its total volume; backed the hay growers in coöperative marketing and in developing the uniform use of U. S. alfalfa hay grades, by which quality was standardized and returns improved; and obtained for lettuce and cantaloupe growers and shippers a federal inspection service which aided them materially in producing packs of standard quality for building up national distribution.

This work of standardization of farm products, indeed, proved one of the most valuable efforts carried out through farm organizations themselves, and with aid of the University of Arizona's agricultural extension service. Uniformity of grade has since proved one of the most important factors in marketing the products of citrus fruit growers, cotton and alfalfa growers, egg producers and other groups. In the case of lettuce and cantaloupes especially, in producing which Arizona now ranks second only to California, the results of the optional federal inspection service led to passage of a state standardization act requiring inspection of all shipments, so that only quality perishables could be shipped and national markets protected, with benefit chiefly to growers themselves.

Where the "Use Arizona Products" idea could do most, however, was in the case of the great variety of farm and manufactured products grown or made principally, or entirely, for the state market. In the aggregate such products made up a large proportion of the total, affecting thousands of producers. Then, too, since they could not be shipped economically to distant markets, they could not be sold at all except near their points of origin. In the case of such products, of course, the standardization just mentioned proved a valuable aid, but the basic difficulty was in direct marketing.

Many peculiar, but easily understandable, circumstances were brought to light when the "Trade at Home—Use Arizona Products" movement got well under way. In the fall, Northern Arizona shipped potatoes into California, while Southern Arizona shipped potatoes in from California. In the spring, several southern sections were marketing potatoes in each other's own localities, glutting some markets while neglecting others. Arizona flour mills supplied the only feasible market for Arizona wheat, but wheat growers themselves were buying outside brands of flour. During the war the sudden rise of cotton-growing had reduced the state's once agriculturally predominant dairy industry to one-fourth its former size, but the same number of creameries were trying to operate despite the increased overhead of low production. Some sections were shipping eggs to distant centers while others were importing them from equal distances. Mining companies were obtaining nearly all of their supplies outside the state, because they had never been given any assurance they could obtain their requirements from nearby distributors, and in some cases, manufacturers.

Mere preaching of "Use Arizona Products" was not enough here. It was easy to sell large industries, such as the mines, on the fact that they had an interest in keeping all the business they could in state channels. It was not difficult to interest a large part of the public in giving home firms and home products a trial. But the Industrial Congress had to go farther and effect a real coördination.

Through its member organizations, it showed producers in different sections how they could allocate markets, avoid duplication and glutting, and make more money not by "stinging" the consumer, but by eliminating their own waste and losses. It aided in several consolidations of manufacturing plants, which cut down overhead and simplified distribution. It hammered hard at the fundamental requirement of standard quality and satisfactory service at a competitive price. It brought producers and distributors together. It enlisted coöperation of the railroads in voluntarily making rate adjustments which would widen distribution territory.

One of the most effective steps was initiating an annual "Buyers and Sellers" conference of mine and industrial purchasing agents, manufacturers, distributors, mercantile buyers and producers' representatives, which in its yearly stages has produced an astonishing amount of business. The Industrial Congress reasoned, rightly, that the main trouble in the past had been a pure lack of contact and understanding between the different groups. Larger buyers did not know what they could obtain within the state, or if they could obtain it satisfactorily. Producers, manufacturers and jobbers did not know the exact requirements they should meet. Once they were all brought together, they could tell each other just what they had to have, or had to offer; make any adjustments that might be necessary or feasible, and lay a friendly basis for future business.

Two typical examples will illustrate how the "Use Arizona Products" theory worked out. When the Industrial Congress was formed creameries were paying dairymen 31 cents a pound for butterfat in No. 1 cream. A year later they were paying 52 cents. The answer was that they had improved their products, been enabled to command the state market by quality instead of price-cutting, and were making money themselves.

Soon after, and again a few years ago, a poor cotton market one season led to a pronounced increase in wheat planting the next year. Flour mills were expected to buy 50 per cent more wheat than they had been milling; there was no other market. The Industrial Congress brought growers and millers together, placed the facts before business firms, waged a vigorous campaign throughout the state which demonstrated that the increased amount of flour could be sold, and mills bought the crop at a price materially above the world market.

Perhaps it might be mentioned here that the "Trade at Home—Use Arizona Products" principle was urged entirely without prejudice against outside commodities or business, and merely as a matter of efficiency and common sense. There was no reason why Arizona should be exporting and importing the same things at the same time. There was every reason it should not. No attempt was made to erect a barrier against outside products or firms. It was merely a question of doing business in the most simple and most logical way, for the benefit of all concerned. The Industrial Congress showed producers and business men how they could take advantage of natural and legitimate opportunities, and helped them to get a start.

The idea of "Buy in Arizona" took hold. Naturally—since it is not a manufacturing state to any material extent—many things could not be bought from Arizona producers. They could, however, usually be bought from Arizona jobbers. To what extent the movement popularized itself, and to what extent it led to a wider variety of products, a higher standard of quality and service, may be judged from the fact that in the past eight years the movement has kept in Arizona channels an average of $20,000,000 worth of business annually that formerly went outside the state.

In accomplishing this result, coördination of industry must receive a large share of the credit. In its great mining industry, its large railroad operations, its important lumber, utility and similar industries, Arizona had available a great concentrated purchasing power. It was placed at the service of Arizona business and producing industries to as full an extent as it could be used, subject only to the requirements of sound business practice.

As the effects of the post-war depression wore off and conditions improved, the Industrial Congress expanded its work to cover a broader development field. Research, surveys and business analyses had been employed in making the "Trade at Home—Use Arizona Products" principle a sound business program, and inevitably they paved the way for expansion and new development. One forward step led to another. When a large meat packing industry was aided in establishing itself in state-wide markets, it was logical for it to add a cottonseed oil refinery to its plant and go into the manufacture of vegetable shortening. When a large distributing firm was enabled to cover the state adequately it naturally found opportunity to add new stocks which in the past had not been carried.

In this way the Industrial Congress was responsible for many industrial and business expansions. It went farther, as its surveys showed there were new industries which might be established to serve state markets. Not always large industries, but important in the aggregate. It interested capital in establishing an oxygen plant, an acetylene plant, a broom factory, and a water-softener plant. It aided other capital in establishing a garment factory, a mattress factory, canneries, brick plants, alfalfa mills and a variety of other plants. Presently a million dollars annually had been added to payrolls by just such new establishments. A million dollars isn't much in some places, but it is welcome in a state which has only 100,000 families.

Tourist travel was another form of new development that early engaged the Industrial Congress' attention. Highway construction and improvements were opening up rich new scenic areas in many different parts of the state, many of which were little known despite the constantly growing popularity of such outstanding wonders as the Grand Canyon, the Painted Desert, the Petrified Forest, the Roosevelt

Dam and Apache Trail connecting it with Globe and Phoenix, several famous cliff dwellings, and two remarkable old Spanish missions. Moreover, Arizona's previous tourist development had been somewhat one-sided. Southern Arizona was becoming nationally-celebrated as a winter resort area, due to its extremely mild climate, but scarcely anyone realized that Northern Arizona and Eastern Arizona, with their high mountains, trout streams, numerous small lakes and heavy forests, had very attractive summer-resort possibilities.

In surveying these possibilities the Industrial Congress was struck by the fact that a very large percentage of Arizona people were in the habit of spending a large part of their summers outside the state. In conjunction with chambers of commerce and automobile associations, it launched a "See Arizona First" movement to educate Arizonans to the summer vacation attractions of their own state. Within a year the campaign had made such progress the slogan had to be shortened to "See Arizona"—so many people had seen Arizona "first" that the problem now was to show them they could see it again and again without covering the same ground twice.

At once new summer resorts began to spring up. New summer colonies were established. In some sections guest ranches that had been operating only through the winters began to feature summer seasons also. Newspapers, as in the "Trade at Home—Use Arizona Products" movement, were enthusiastic supporters of the perennial campaign. Soon Arizona resorts and resort sections found they were entertaining more and more out-of-state visitors each year. The scores of thousands of motorists crossing Arizona to or from California had "discovered" the new territory and were spending more time in it. Resort development begun by Arizona residents themselves was paying millions of dollars in business dividends each season, because wider advertising and improved accommodations were attracting outsiders as well as keeping Arizona vacation money "at home."

In the course of this work, the Industrial Congress remained a clearing-house for the other organizations of the state, and through them it was called upon to aid in establishing a number of new hotels, resorts and guest ranches to keep up with the increasing tourist travel to all sections. In a few years alone fourteen new hotels, ranging in size from modest proportions to 15-story structures, were built in nearly as many cities.

As conditions improved and general development gained pace, as they did rapidly after 1922, the coöperation of industry brought about by the Industrial Congress began to be manifest in other directions and in larger projects. When the Salt River Valley Water Users' Association, operating the famous Roosevelt Dam project surrounding Phoenix, began to develop the Salt River's power resources, it already had contacts with mining companies in nearby counties which made it easy to contract for the sale of the additional hydro-electric power to be developed. With such contracts, financing the proposed new dams was not difficult. Since 1923 the association has built three new power dams below Roosevelt Dam, and with normal water supplies its increased power revenues will be sufficient to pay all operating, maintenance and construction repayment charges of the entire project.

Yet in reality it was coöperation between farmers, through their organization, and mining companies, that made this power development possible.

Advisory and research service of the Industrial Congress also became a factor in a number of new irrigation projects built in Arizona in the past few years. As one example, when a bill was before Congress to authorize government construction of the San Carlos Project, of which the Coolidge Dam was dedicated last spring, the Industrial Congress was called upon to submit evidence that the new land to be irrigated would not conflict with existing farm areas, and that transportation facilities and markets were available for the products to be grown. Within two days the desired data were on the way to Arizona's senators and representative, to assist them in working for passage of the bill.

As this new agricultural development gained momentum, with more irrigation projects built, building or proposed, the Industrial Congress began to direct attention to the problem of colonization. In a few years Arizona would have a quarter of a million acres of new irrigated land ready for cultivation. Most of it was owned by present residents who for the most part would be unable to farm it themselves. If it were made productive it would add very materially to the state's producing and purchasing power and to taxable wealth; if it were not settled and made productive rapidly, it would tend to depress existing land values. Moreover, existing irrigated districts were not as closely settled and as intensively productive as they might be. Altogether, it was figured Arizona could absorb more than 20,000 families on farms by, say, 1932. Such an increase in farm population would allow a corresponding increase in urban population.

Real estate boards, land project representatives, chambers of commerce, railroads and other interests were brought together to consider the colonization question. The aim was to accomplish the most with minimum cost and minimum duplication of effort. A long-time program was needed, rather than a sudden intensive one. First, arrangements were worked out whereby the several communities maintaining national advertising clubs devoted more and more of their advertising to agricultural possibilities. Along with that, chambers of commerce, advertising clubs and similar bodies began following a policy of giving all their inquirers information covering the entire state. The Santa Fe and Southern Pacific railroads naturally were keenly interested, and the Industrial Congress worked out arrangements with them whereby they began to include a more direct type of Arizona advertising in their regular national advertising programs, with resulting inquiries available to the Industrial Congress and chambers of commerce for follow-up.

The Industrial Congress recently estimated that the advertising being given Arizona by railroads and corporations of the state now equals in effect a state advertising campaign costing several hundred thousand dollars a year. Yet, by coördination, it is costing nothing in the way of added expenditures.

Another interesting phase of the Industrial Congress' colonization and advertising work lay in the coördination of trade relations it incidentally developed between Arizona and Southern California. The Industrial Congress had noticed, as everyone no doubt had noticed, the great amount of national advertising being carried on by Southern California. It also had noticed that no special effort had been made to form close trade relations between the two states, though Arizona was naturally a part of Los Angeles' potential trade territory in its eagerly-sought industrial and commercial development. It occurred to Spilsbury that the two—advertising and trade relations—might be linked together to mutual benefit.

Spilsbury made a survey to see what other western states, or more particularly the Pacific coast port cities, were doing in the way of trade relations and inland development. Vancouver and Seattle, he noted, were bending every effort to develop their respective "back countries" to further their own industrial growth and foreign commerce. San Francisco had long cultivated a trade territory extending as far as Salt Lake City. Financially and economically these ports had linked themselves with inland regions.

It seemed to Spilsbury that Los Angeles could do a great deal along this line. Southern California was fast moving beyond the period of agricultural development to a period of industrial development. Its problem was becoming one of large-scale manufacturing and distribution and commerce. It needed the Arizona trade territory for its industrial growth; in time would need more of Arizona's basic products. Yet about 80 per cent of Arizona's basic commodity production was going east—as was practically all of Arizona's business in finished commodities that were not made in the state.

The Industrial Congress took up the possibilities with the Los Angeles Chamber of Commerce and Southern California business leaders. It proposed that Southern California include Arizona's farm opportunities in its national advertising work, and offered in return to support California in bidding for more of Arizona's business that was going outside the state. The Californians responded; the Los Angeles chamber set up a special Arizona relations committee, and the interstate coöperation worked. Scores of thousands of pieces of Arizona literature were distributed from Los Angeles exhibits in the East and at Middle West state fairs, thousands of inquiries received, and some millions of dollars worth of new business was developed in Arizona by Southern California interests.

A particularly notable instance of the larger application of coördination of industry occurred last winter following the discovery of the cotton pink bollworm in the Salt River Valley. The Salt River Valley is the state's largest agricultural area; cotton-growing is Arizona's leading agricultural industry in point of value; and due to exceptionally favorable climatic conditions for the pest's propagation, the bollworm constituted a distinct menace. Entomologists warned that if it were not eradicated at once it would spread to other farm districts, soon destroy the cotton industry, and undoubtedly lead to embargoes against many other Arizona field crops in other states. The situation held possibilities of real disaster.

The cotton bollworm, it might be explained, is not the boll weevil. Unlike the weevil, it is not prevalent anywhere in this country. Of the two pests, it is the more dangerous in some respects, for the bollworm becomes a moth and, therefore, can spread with remarkable rapidity. On this account its appearance in any state is followed by prompt eradication steps by the U. S. Department of Agriculture. Ordinarily this consists of a thorough clean-up of all affected fields and a single season's quarantine, for the bollworm larvae can not survive from one season to another where winter temperatures go below 28 degrees.

Here the Salt River Valley's winter-resort climate proved a handicap. Department of Agriculture experts surveyed the valley at once to plan an eradication program, but they reported that it could not be undertaken unless the state set up a non-cotton zone covering all the infested area, in which no cotton could be grown for three years.

This complicated Arizona's problem. Unfortunately, a non-crop zone can not be maintained unless growers are reimbursed for any necessary and unavoidable losses they may be forced to undergo in growing less profitable crops. Government policy in such cases had been pretty well established: the government had been providing half of such funds needed for growers' compensation, in addition to providing funds for the expense of the eradication "clean-up," on condition that the state affected put up half of the compensation fund itself. But Arizona, with its small population and large area for which roads and schools and other improvements must be provided, had its budget too carefully balanced to have funds in its treasury to match a government compensation fund on such short notice.

A state delegation including heads of farm organizations and the Industrial Congress was sent to Washington to see what could be done to meet this emergency. Bills already were before Congress to authorize an appropriation of $587,500 for eradication of the bollworm, and appropriations of up to $2,500,000 for compensation in states in which non-cotton zones might be necessary. The Arizonans pointed out that the state's half of the necessary compensation fund could be provided only by the legislature, which would not hold a regular session until January, 1931; that if a special session were held with its attendant added expense, funds still could not be forthcoming in time to match a government appropriation for eradication to be completed before the summer danger season.

Secretary of Agriculture A. M. Hyde accordingly agreed to support a provision in the appropriation bill authorizing the government to advance all of the compensation fund needed for 1930, if Arizona through its legislature or through responsible organizations and corporations could make satisfactory guarantees that the state's half of the fund would be repaid to the federal treasury by 1932. This would allow eradication to proceed without delay, and also would allow the state to include its appropriation in a new budget, without undue hardship in the tax rate.

The Arizona delegation returned early in February and the Industrial Congress was given the responsibility of raising a satisfactory guaranty. Total compensation for 1930 was estimated at slightly more than $1,000,000; in 1931 and 1932 it would be much smaller, for farmers would have had time to establish themselves in other crops. But someone must pledge half a million dollars as security that the state's half of 1930 compensation would be repaid, and it must take the form of a direct financial pledge, for no guaranty could be given on behalf of a state government whose appropriation must come from a legislature not yet elected.

The Industrial Congress put the problem before Arizona's industries. Simultaneously it referred it to all other interested agencies. Within a week virtually every organization in the state, the Democratic and Republican state central committees, and nearly all members of the present legislature had gone on record as favoring the eradication program with the compensation it entailed, and pledging themselves to support the necessary legislation at the next session to repay Arizona's half of the 1930 fund.

Within two weeks Secretary Hyde was notified that responsible organizations and corporations had signed financial guaranties aggregating $500,000 which were on the way to his office. By the end of February the government's funds for eradication were released; by the end of April the 47,000-acre bollworm-infested area had been cleaned up, stalks and rubbish burned, soil deeply plowed and irrigated to destroy all larvae, and the job was finished with appointment of a commission to determine how much farmers actually would lose through having to plant other crops than cotton, and so late in the season.

The guaranty that made this possible consisted of individual pledges, ranging in amount from $5,000 to $75,000, whose guarantors included the Salt River Valley Water Users Association, an adjoining irrigation district, two railroad companies, six large mining companies, a lettuce shippers' association, four cotton companies, a newspaper, and four industrial firms. In this diverse list is a typical illustration that coördination of industry *works*.

Other instances of coördination of industry—practical coöperation in industry and between industries—could be presented until they filled a volume. It became a habit in Arizona to think first of the Industrial Congress when any economic problem arose—no matter if it affected one small business firm, a group of great corporations or a thousand farmers. During the past eight years the organization's work has touched every conceivable form of agricultural, business, industrial and professional activity and every possible branch of new development. Although it remained essentially the clearing-house, doing its work through and with all the other organizations representing different industries and sections of the state, it took advantage of every opportunity by which Arizona might benefit in any way. Last year alone Arizona received national publicity which represented $200,000 worth of space, because the Congress was alert to have material and illustrations ready whenever anything pertaining to Arizona seized popular interest.

Perhaps the most outstanding of its accomplishments has been its ability to do so much purely along economic lines without once touching on the political. The Industrial Congress and its leaders reasoned simply that business could attend to its own affairs and adjust its own difficulties without resorting to politics, and that if business men couldn't solve business problems they couldn't expect politicians to solve them. Thus, although it has coöperated time and again with governmental agencies, state, county and local, that inevitably are political in character, it has never had the handicap of partisanship.

Today the Arizona Industrial Congress is an institution in Arizona. Spilsbury is still its president and active head. Its budget is the same $30,000 annually set in its first year; its staff still consists only of a secretary who is also manager of trade extension, a manager of research and public information, and three stenographers. Its scope and operations have broadened steadily, but in its capacity of clearing-house, gaining its results through others, it has been able to keep up with its demands. Its reports still list as its basic policies the following principles laid down in the beginning:

(1). To help all existing organizations to function most efficiently for their individual members.

(2). To create markets nearest the point of origin for all products, and to retain all business possible in local or state channels.

(3). To determine the amount of excess production over local needs and distribute this excess.

(4). To encourage the highest quality of production and service to minimize effects of outside competition by quality, not by price-cutting.

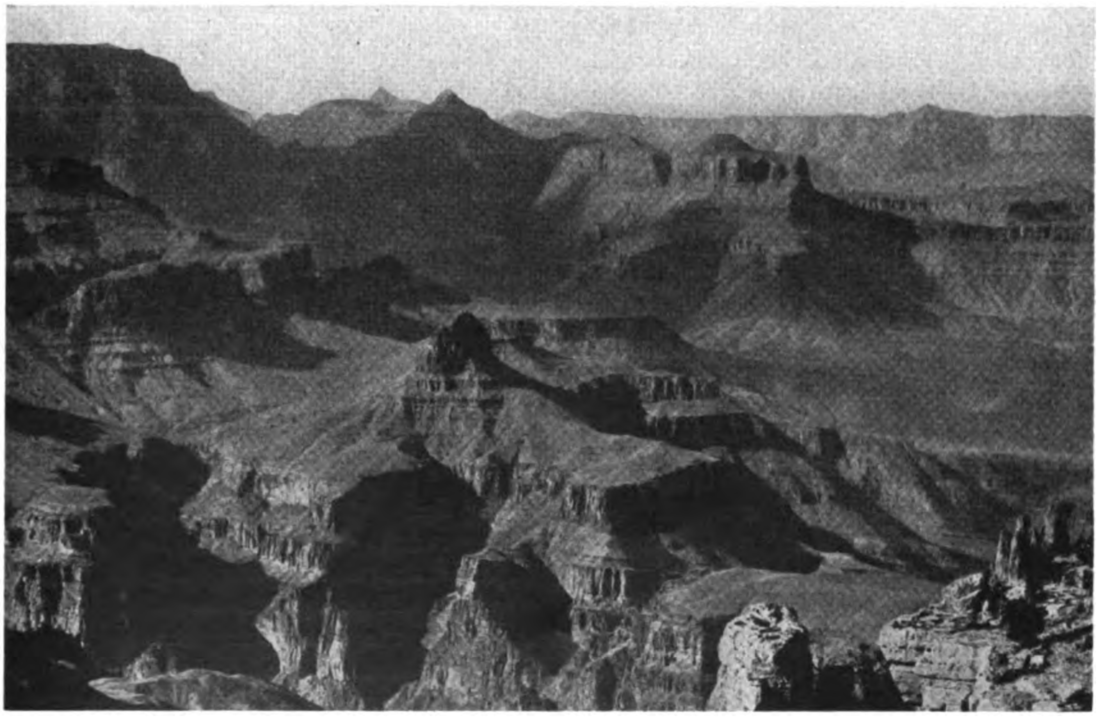
(5). To crystallize public sentiment on constructive problems by presentation of facts and exchange of ideas between organizations.

(6). To help ourselves and our state by creating a loyalty to home institutions with a united slogan of "Forward Arizona."

Several times in these past eight years Arizona has weathered, without noticeable effect, economic shocks that would have meant a pronounced slump in previous years. At the present time, though undeniably feeling the effects of national conditions, it's business leaders claim it shows less evidence of depression than perhaps any other single state. Since 1922 its bank deposits have increased more than 40 per cent; checking transactions have increased more than 50 per cent; area of irrigated land has increased 25 per cent; value of all farm crops has increased around 100 per cent; value of mining production has increased 50 per cent; lettuce shipments have increased from 1,000 cars a year to more than 9000; cantaloupe shipments annually have mounted from 1000 cars to nearly 6000; tourist travel into the state has doubled; and more than $100,000,000 has been invested in new irrigation, mine and railroad projects, plus another $100,000,000 invested in building construction of all kinds.

Not a bad record, perhaps, considering that Arizona still has little more than 400,000 people, including Indians and Mexicans.

And this, in brief, is the story of the Arizona Industrial Congress, the "Arizona Plan" represented in its organization and operation, and how it has applied coördination of industry in a practical way to the economic development of a state. Quite naturally, many of its features were automatically determined by special conditions in the state itself; the general principles, however, should be applicable to any section. The New England states are probably as different from Arizona as any territory could be, but New England's organization is working along remarkably similar lines. Mexico, Western Australia, Great Britain and several of our own states have sent to Arizona, the youngest commonwealth, for data as to its coöperative economic agency. But whatever may be developed elsewhere, Arizona has demonstrated to its satisfaction that Industrial Coördination is possible and practical—and that it pays.



ARIZONA—A Territory Containing so Many Natural Wonders That No Pen Has Yet Rendered a True Description of Them or No Brush Yet Succeeded in Painting More Than a Fleeting Picture of Their Ever-changing Enchantment

Recent and Possible Future Developments Affecting the Economics of Large Steam Turbine Practice in the United States

PART I

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(A paper presented at the World Power Conference, Berlin, Germany, June 16-25, 1930)

THE general trend of large steam turbine development, as it bears on the economics of power-plant operation in the United States, will be described in this article with particular reference to the designs of the General Electric Company.

There have been the following definite trends clearly observable:

(1). Increased unit capacity, with resultant concentration of capacity with respect to floor space and reduced turbine and building costs.

(2). Increased output per square foot of last-stage bucket area, with resultant higher leaving losses but lower turbine costs.

(3). Design and operation on much more efficient heat cycles.

(4). Increased efficiency of the turbine generator as a result of more experienced and more scientific design; together with the increase in efficiency which has resulted from the increased capacity.

This is a picture of the situation as it appears in the latter part of 1929. The art is developing so rapidly that conditions in the near future may appear appreciably different.

PRESENT SITUATION

The past five years has been a period of intense development and change in the power industry. The great progress which has been achieved has resulted from the fact that the best minds of financing, managing, engineering, and manufacturing groups, many of them specialists in their fields, have been concentrated upon the problem of securing an adequate supply of power at as low cost as possible.

In practically all of the studies which have been made by plant designers to determine what arrangement and type of equipment should be used in a new station, the economic situation has been uppermost. The designs which have been finally adopted have shown good possibilities of producing power more cheaply, under the conditions prevailing in the particular localities considered, than could be done with any of the other designs.

When consideration is given to the wide difference in these conditions, together with the different mental attitudes of the men making the studies, it is not strange that there should be many widely different arrangements, using different pressures, temperatures, resuperheat cycles, types and sizes of turbines, boilers, etc. Some power-plant designers have pioneered in one direction, some in another; some have been more conservative, and have sought by skillful design to reduce first cost and to consolidate more thoroughly the ground already gained. Quite often it will work out, however, that either one of two widely different types of plants will be equal in overall cost of power. That is, under the conditions prevailing, the increased fixed cost of the more efficient station will just balance the reduced operating costs. Under these conditions, the decision will have to be made on the basis of less tangible factors, such as: (*a*) desire to advance and to lead the industry by using the newer type of equipment in the hope that subsequent installations

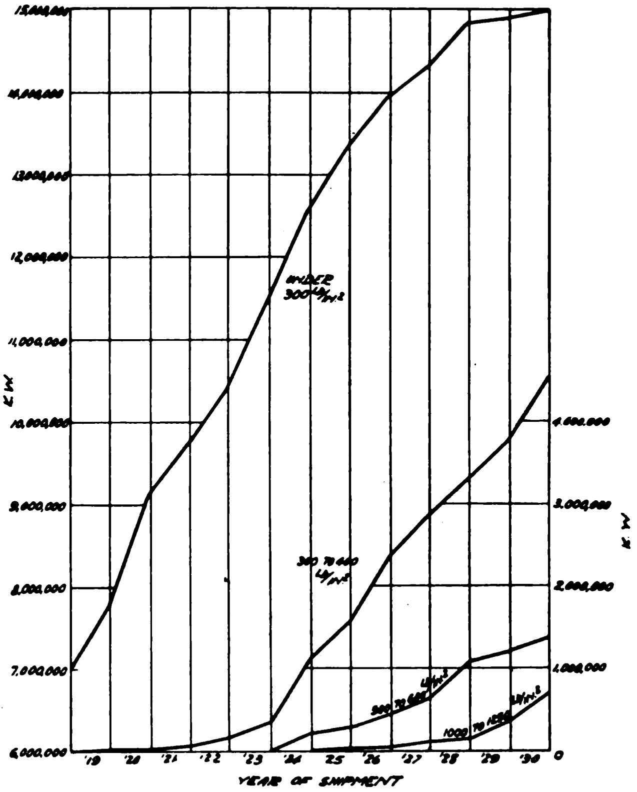

Fig. 1. Cumulative Capacity which Has Been Built in Four Pressure Groups. General Electric steam turbines of 10,000-kw. capacity and over

will have a lower first cost; (*b*) desire to solve one particular phase of the problem of better plant design; (*c*) desire to avoid, for obvious reasons, the introduction of new and not yet completely proved types of equipment.

In connection with the conservative viewpoint last noted, the following point has been given serious consideration. The useful life of a plant is determined by its obsolescence; very few plants wear out. Obsolescence is relative to the other plants in a system. Consequently, a design which is too conservative will become obsolete sooner than would one of more radical design.

It is worth while to notice that the rapid progress which has been achieved in this country has been made in steps that have not been so large as to go beyond the possibility of producing reliable equipment. Each step, although large from some viewpoints, has not gone so much beyond experience as to lead to the incorporation of many untried elements in the vital parts of the construction. The result has been that all stations of new and untried designs have been successful commercially, and are running in regular commercial service today.

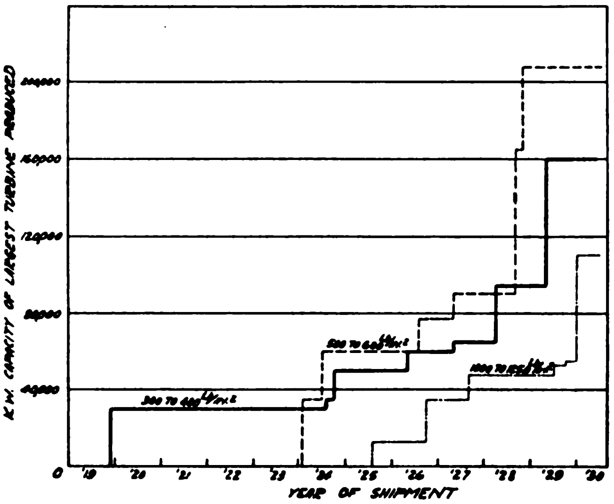

Fig. 2. Maximum Size of Unit Manufactured or on Order for Three Pressure Groups. General Electric steam turbines

The art is still progressing very rapidly, and the indications are that it will continue to do so indefinitely.

Fig. 1 shows the cumulative kilowatt capacity which has been built in four pressure groups. This chart shows quite plainly the increasing attention being given to the higher pressures; the way pressures below 300 lb. per sq. in. are being installed at a reduced rate; and the way in which the 300 to 400 lb. per sq. in. group is holding its own.

Fig. 2 shows the maximum size of unit which has been manufactured or placed on order for three of the groups of turbines recorded in Fig. 1.

Fig. 3 shows the comparative economy of three pressure groups as a function of capacity, this representing the conditions of three-fourths rated load and the machines constructed in general as they have been made. Specific conditions may modify these values.

Fig. 4 shows the comparative cost of the various types of turbines as a function of their capacity.

The real factor seems to be the number of cylinders and the speeds rather than the pressure, and so a high-pressure machine is more expensive than a lower pressure machine primarily because it usually has a larger number of cylinders.

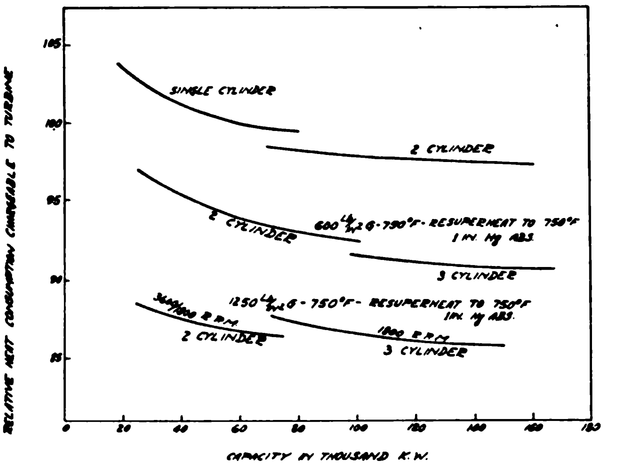

Fig. 3. Approximate Change in Most Economical Heat Consumption with Change in Turbine Capacity for 400, 600, and 1250 lb. per sq. in. Cycles

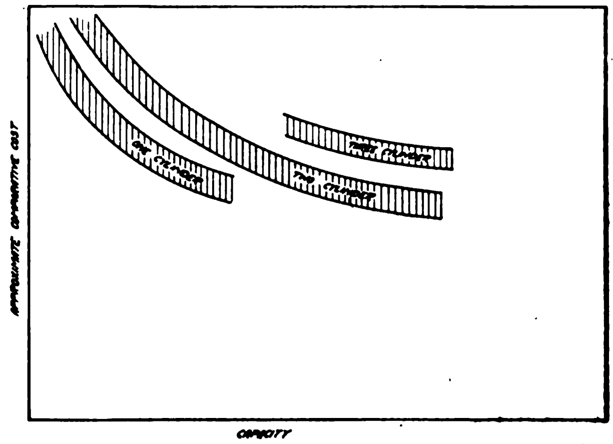

Fig. 4. Comparative Cost of Various Types of Turbines as Function of Capacity

Fig. 5 shows the overall length of turbine-generator sets as a function of the capacity and type.

Fig. 6 shows the floor space in sq. ft. per 1000 kw. required for the preceding groups of machines.

Single-cylinder vs. Two or Three-cylinder Turbines

It is generally recognized that, excellence of design being equal, the two and three-cylinder turbine is a somewhat more efficient but a much more expensive machine than a single-cylinder turbine. The gain in efficiency is particularly marked with higher initial pressures, or in case the capacity of the single-cylinder single-flow turbine has been pushed up so as to increase the leaving loss unduly.

The two and three-cylinder turbines require in general somewhat more space, and more expensive foundations and buildings. Another factor which has favored the single-cylinder design has been the rapid growth in the electrical demand in this country, carrying with it the necessity for rapid extensions of power plants. This has often made necessary the installation of unit sizes in the extension from two to four times those contemplated in the original design. Such requirements have, of course, placed a great premium upon obtaining the greatest possible capacity from a given space, and ofttimes from a given length. These factors, coupled with the strong tendency on the part of American operators and plant designers to favor single-cylinder designs from the operating viewpoint, have naturally resulted in a strong preponderance of such machines up to sizes which can be built economically in the single-flow type.

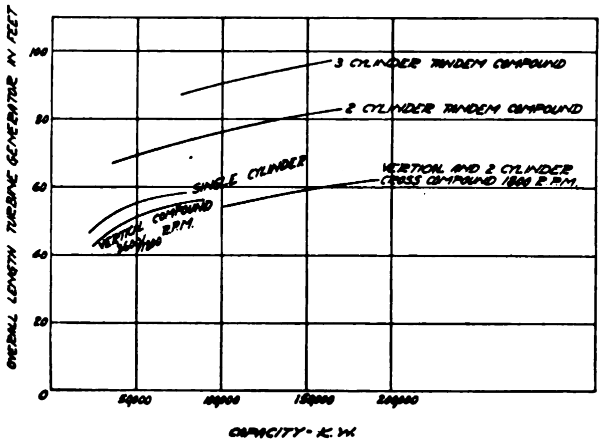

Fig. 5. Overall Lengths of Turbine Generators of Various Types as Function of Capacity

These considerations have forced the development of single-cylinder turbines to a very high degree of perfection in the United States. Up to capacities of 80,000 kw., where the pressure is less than 550 lb. per sq. in. and the temperature less than 750 deg. F., it is almost impossible to justify economically the more costly two or three-cylinder designs. The company with which the writer is associated, by concentration upon the design of single-cylinder turbines where conditions are proper, has been able to produce a turbine which has an extremely good efficiency over the useful load range. Being inherently simple, rugged, and low in cost, these have been very successful machines.

On the other hand, early attempts to build 600 lb. per sq. in. resuperheat machines single casing, while entirely successful from the operating standpoint, showed the desirability of dividing the turbine at the resuperheat point, which has been done on all succeeding designs. Both two and three-cylinder tandem-compound and cross-compound machines have been constructed or are under construction. At present, higher-pressure machines must of necessity be divided, often running the high-pressure turbine at double the low-pressure turbine speed, *i.e.*, at 3600 r.p.m. with the low-pressure machine at 1800 r.p.m.

In connection with 1200 lb. per sq. in. and higher-pressure plants, there is somewhat of a difference in opinion as yet as to just how the high-pressure turbines should be arranged. The consensus of opinion, however, seems to be as follows: Where the 1200 lb. per sq. in. cycle is installed as an addition to a station already having low-pressure units and where it will have a high load-factor, the new addition should have as many high-pressure noncondensing turbines as there are boilers, each turbine discharging through the resuperheater in its own boiler at constant pressure into the original low-pressure header to which the new low-pressure turbine is attached, the high-pressure flow being governed by the pressure requirements in the low-pressure header. On the other hand, in a new station many think that the high and low-pressure turbine should be a cross or tandem-compound machine with the entire governing of the unit on the high-pressure turbine and the crossover pressure fluctuating with the load. The former arrangement is deemed by some to be a simpler one to operate and to be highly efficient as a base-load unit, whereas the latter may secure a cheaper and somewhat more economical unit where lower loads must be carried at times.

Vertical Compound

In a few cases where station conditions seem to warrant it a new form of design called "vertical compound" has been used. Two of these designs are shown in Figs. 22 and 23. Two different arrangements are used. One is typified by the Jersey Central Power and Light Company and the Pacific Gas and Electric Company machines which have had the high-pressure turbine and generator mounted on top of the low-pressure generator. In this case the high-pressure turbine has been slightly under 25 per cent of the capacity of the entire unit, has operated on 1200 lb. per sq. in. steam pressure, and has been arranged for boiler resuperheating to the initial temperature

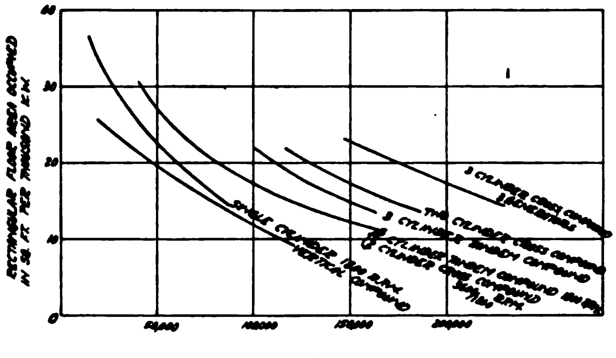

Fig. 6. Rectangular Floor Area Occupied by Turbine Generators of Various Types as Function of Capacity

between the units. These conditions are not necessary of course, but the high-pressure unit should be less than 25 per cent of the total capacity to permit of this arrangement being used. The other arrangement is typified by the Ford turbine in which the high and low-pressure turbines are sufficiently close in output to permit identical generators being used, in which case the two generators are mounted one on the other, and the high-pressure turbine is mounted on top of the low-pressure turbine. In the Ford installation the pressure is 1200 lb. per sq. in. with resuperheating by means of live steam to 550 deg. F. between the two units. This arrangement is quite easily adapted to other steam conditions wherever a cross-compound machine can be divided approximately equally.

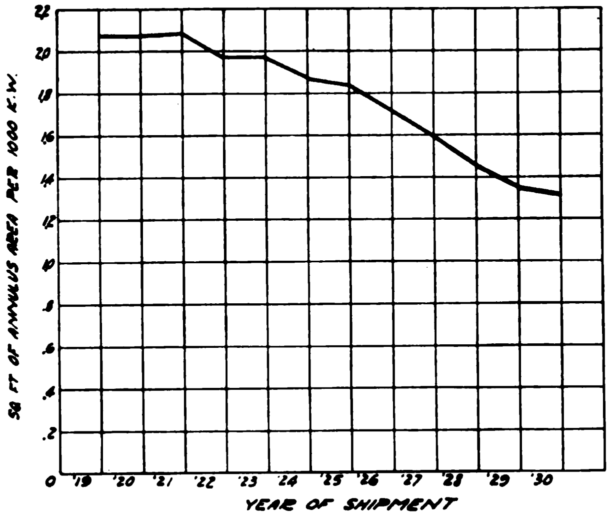

Fig. 7. Average Number of Square Feet in the Last Stage Annulus Area Per 1000 kw. of Turbine Rated Capacity, Based on All General Electric Turbines Shipped, Showing Increasing Capacity which Has Been Obtained from the Low-pressure End of Turbine

Special precautions have been taken to guard against differences in expansion between the supports of the upper turbine and generator, and to permit ease of dismantling the low-pressure machine.

The saving in space and foundations which such arrangements make is obvious. In the case of the Ford machine, this 110,000-kw. unit is being placed in the same building, with the same spacing between units, as had previously been used for the 12,500-kw. unit which is being removed. In the Jersey Central unit, the vertical compound arrangement will permit the placing of three identical units in the space originally allotted to two cross-compound units of the same capacity.

Increase in Capacity Obtained from Low-pressure End

It is of course generally recognized that one of the controlling elements in turbine design is the low-pressure end, *i.e.*, the last wheels, buckets, and exhaust hood. The capacity which can be obtained from the low-pressure end of a given turbine is limited by the leaving loss. As pressures and temperatures have been increased, however, and resuperheating and regenerative feed-water heating cycles have been adopted, more and more total turbine power has been obtained for a given quantity of steam flowing through the last stage. Furthermore, as more power is produced for less cost it becomes economical to increase the leaving loss somewhat. Two other factors tending toward the same result have been: first, the increasing number of sales of turbines in the southern states where vacua cannot be so high; and second, the desire for greater capacity within given building limitations. All of these factors have tended to increase the capacity which has been obtained from a given last-bucket annulus area as is shown in Fig. 7. This increased capacity obtained from a given exhaust-wheel area has been a big factor in decreasing turbine costs. On the other hand, this rating up has been carried sometimes to such a point as to seriously increase the leaving loss, and so reduce the overall efficiency below what could have been obtained with larger and more costly low-pressure ends.

SELECTING A TURBINE UNIT AND THE STEAM CONDITIONS

The turbine is but one part of the complete power plant. It represents about 15 to 20 per cent of the total investment. Many things have to be taken into consideration before a wise decision can be made as to what is the best solution for a particular problem. The value of the newer developments must be determined. In the initial considerations of a new plant or addition to an existing plant, two questions must be settled at an early stage of the work: first, what size and type of turbine unit will be installed; second, what steam conditions will be used. Until these questions are settled it is impossible to proceed with the station design. In general, the ultimate capacity of the station is a matter that does not have to be settled until several units have been installed and the character of the future load determined. Such elements as load-factor, cost of coal, and cost of the complete power plant have to be weighed very carefully. This investigation on the part of the purchaser has generally made necessary the furnishing of several studies by the turbine builders and the plant designers before the final arrangement is agreed upon and bids asked for from equipment manufacturers.

Economics of Choosing a Turbine Capacity and a Turbine Size

Formerly, when power stations were isolated, the capacity of a prospective turbine installation was practically settled by the load available and the necessity of splitting the station capacity into a number of units in order to obtain sufficient reliability. While such considerations still carry a great deal of weight, they are not now the predominating factors owing to the interconnection of power stations into great systems. The capacity is now determined more by the economics of the situation, and it quite frequently works out that the most economical machine is the largest that can be installed within the physical limits imposed by the demand for power, buildings already built, or the state of the art.

The total size of the plant has an effect upon its cost per kilowatt, but the capacities of the turbine and boiler units have a more direct bearing upon the cost of a station per kilowatt regardless of the total capacity. For example, as Fig. 4 shows, the cost of all types of turbines decreases per unit of capacity as the size increases. The same trend is in general true of the other equipment. The comparatively small increase in overall length and the great reduction in square feet of floor space per thousand kilowatts of capacity as the capacity is increased are shown in Figs. 5 and 6 which illustrate plainly the economies in station initial investment permitted by large units. Complete analyses of plant costs, made by many groups of engineers and under many conditions of design and location, indicate conclusively that the overall first cost of a station per kilowatt of installed capacity decreases markedly with an increase in the capacity of the turbine-generator sets, and with an increase in the capacity of the boilers used.

The capacity of the unit also has a marked effect upon economy, as shown in Fig. 3.

The decision as to the capacity of the unit which is to be installed must then be governed by the factors of plant cost and economy as compared with the advisability of tying up an increasing fraction of the system's capacity in a single unit. Some engineers and operating groups believe that not more than 10 per cent of the capacity of a system should be put into any one unit that may go completely out of service. This latter element is sometimes met in very large cross-compound units by making provisions for operating one or more parts of the unit separately from the remainder. Such arrangements always seriously complicate the piping, governing, and switchgear designs, make the operation more difficult, and increase the station cost.

The rapid increase in system capacity and interconnection in this country during the past ten years, however, have given station designers ample opportunity to realize the full economies of increased turbine and boiler capacities without jeopardizing system reliability. It is quite probable that this trend will continue, since both turbines and generators at 1800 r.p.m. are still far below the possible limits for tandem or cross-compound machines, particularly when the increase in turbine capacity resulting from better steam cycles and the possible increase in generator capacities with hydrogen cooling are considered.

Capacity of Unit *vs.* Size of Unit

There is a distinction which must be made between turbine capacity and turbine size. Two machines may each have the same capacity, say 100,000 kw., but one may be larger, *i.e.*, may have a larger and more liberal exhaust area, and hence in general a better economy. More material and labor may enter into its construction. It may frequently work out, as shown in the following example, that the larger and more economical machine will give the lower overall first cost of plant owing to better utilization of the investment in boilers, condensers, buildings, etc. The turbine uses not only fuel but the entire invested capital in the remainder of the plant. In addition, it is of course obvious that the more efficient machine will save fuel.

Example

Suppose, for example, a proposed 100,000-kw. turbine has a heat rate of 10,000 B.t.u. per kw-hr. at maximum load. A new power station, or new section of a power station, is now designed around this machine so as not to have any boiler reserves, as is now quite frequently done, and boilers, condensers, auxiliaries, etc. are put in so that at 100,000 kw. they have about the same margin of extreme capacity over the rated capacity as the turbine (as should be done to get the lowest station cost). Under these conditions, at rated load the station will have 100,000-kw. output, or say 110,000 kw. with everything stretched to the limit at improved power-factor operation on the generator. Suppose that to build this station costs $100 per kilowatt of rated capacity or $91 per kilowatt of extreme capacity exclusive of the switchgear, *i.e.*, $10,000,000.

Take, for example, a proposal on an alternative turbine and generator which by virtue of a larger low-pressure end has a two per cent better efficiency at maximum load than the first unit. The better efficiency would be less at the lighter loads. Then if, as should be done, this machine is rated in comparison so as to consume the same steam as the first, it should be called a 102,000-kw. turbine-generator since its increased efficiency will permit it to develop this power with the same steam which the other turbine used to develop 100,000 kw. It now becomes possible to substitute this machine for the first with the same boilers, building, condensers, auxiliaries, etc., and obtain a 102,000-kw. normal station rating or say 112,000 kw. with everything in the station worked to the limit.

If to install a station larger than the original 100,000-kw. station the increment in cost of a kilowatt of installed capacity is $75 per kilowatt, then this extra 2000-kw. capacity so obtained would be worth $150,000. That is, it would cost $150,000 to get this extra capacity in the less efficient plant. The station owner can, therefore, afford to spend if necessary for the more liberal turbine anything up to a limit approximating $150,000 plus his capitalized value of the one to two per cent fuel saving. If the difference in cost is less than the $150,000, the more efficient station will cost less per kilowatt than the less efficient station. A more efficient turbine may then sometimes be warranted even when the load-factor is low and the fuel saving insignificant. A point of diminishing returns is reached of course, and it is the turbine designer's job to see that his turbine designs are not too big or too small for the particular job they are called upon to do.

On the other hand, many factors may alter this. In one case a large turbine was installed with its best economy at approximately 65 per cent of full load and with a lower economy at full load. This turbine was intended to be operated at full load under emergency conditions only, such as when another turbine in the station might be out of commission, and hence, ample steam would be available from the boilers.

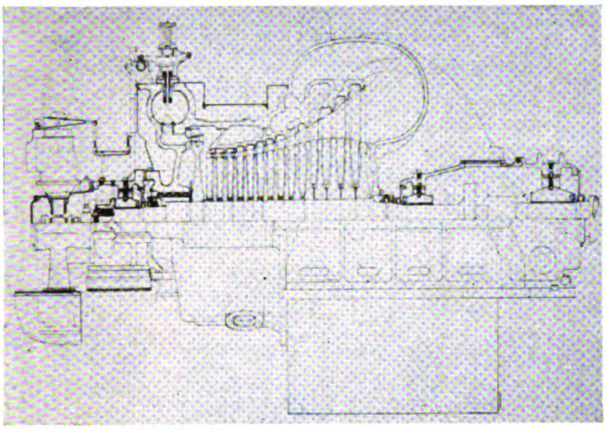

Fig. 8. 25,000 to 35,000-kw. 1800-r.p.m. Single-cylinder Turbine for 300 to 400 lb. per sq. in. Pressure

Furthermore, it often happens that the reduced first cost of plant per kilowatt which can be obtained by increasing the output within given turbine and building dimensions more than offsets the increased fuel charges so obtained. This advantage which can sometimes be obtained by "rating up" a turbine is more apt to be found where to use the next larger exhaust end, and so preserve the efficiency, would mean a two-cylinder double-flow machine of considerably greater length.

For each size of low-pressure end an approximate condenser flow can be worked out and beyond this it is economical to change to the next size. This point, of course, depends upon the conditions that have been outlined and in addition upon the cost of coal, number of years to be operated at good load-factor, vacuum under which the machine is to operate, etc.

On the other hand, if these factors are constant the economical capacity in kilowatts to which a turbine with a given-size low-pressure end can be built depends upon the steam conditions and increases as more economical cycles are used. This will be considered at length later.

Determination of Steam Conditions

Once the capacity and size of the unit is determined, the next question is to determine the steam conditions. This must be based upon the economics of the situation, plus a consideration of the risks that might be assumed if a decision is made to go to conditions which have not yet been completely proved in practice. By very close coöperation between the turbine designers and the plant designers in the initial stages of the design, preliminary estimates of the advantages and costs of different arrangements can be made. Many less desirable solutions can be discarded; then the two or three probable solutions can be studied in greater detail. After the economic factors are settled, a decision can be made by the executives of the plant builders, taking into account the less tangible factors mentioned before, and the steam conditions determined.

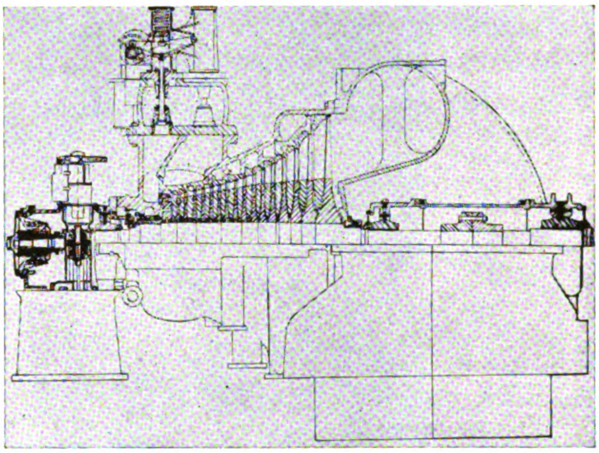

Fig. 9. 80,000-kw. 1800-r.p.m. Single-cylinder Turbine for 425 lb. per sq. in Pressure and 750 deg. F. Initial Temperature

TYPICAL INSTALLATIONS

Some of the turbines which have been furnished after a number of such analyses have been made, and which represent in the opinion of the power-plant designers the best solutions of their particular problems, are shown in Figs. 8 to 23. These machines are typical of the turbines being built by the General Electric Company.

300 Lb. per Sq. In. to 400 Lb. Per Sq. In. Group

Fig. 8 shows a cross-section through a modern high-efficiency single-cylinder turbine for 25,000 to 35,000 kw., built for the 300 to 400 lb. per sq. in. pressure range. This machine is very economical, compact, and low in cost for its capacity. It is easily adapted to moderately high temperatures; and it seems to fill very admirably the requirements met in a large number of instances.

Fig. 9 shows a large single-cylinder machine for 80,000 kw. at 425 lb. per sq. in., 750 deg. F. and 1 in. abs. back pressure. This machine is being installed in a station of low load-factor, operating in conjunction with water power; and, although its leaving loss is moderately high, it was chosen in preference to a slightly more efficient double-flow tandem-compound unit proposed as an alternative for this station. Its lower cost, together with economies permitted in the station building, more than offset its slightly higher steam consumption.

Fig. 10 shows a cross-section of a large tandem-compound single-shaft machine. This is the 94,000-kw. 1500-r.p.m. turbine of which there are two in the Long Beach Plant of the Southern California Edison Company. The first unit went into operation in June of 1928, and the second was placed in operation in the early part of 1930. The first unit produced 75,000 kw. per hour on the average for every hour of the seven remaining months of 1928 after its installation and 86,000 kw. per hour for every hour of the first nine months of 1929. During 1929 the heat rate of this entire station (with 400 lb. per sq. in., 725 deg. F. steam conditions, and about 1¼ in. Hg. abs. back pressure) was 12,880 B.t.u. per kw-hr., based on send-out, with oil fuel. (1)

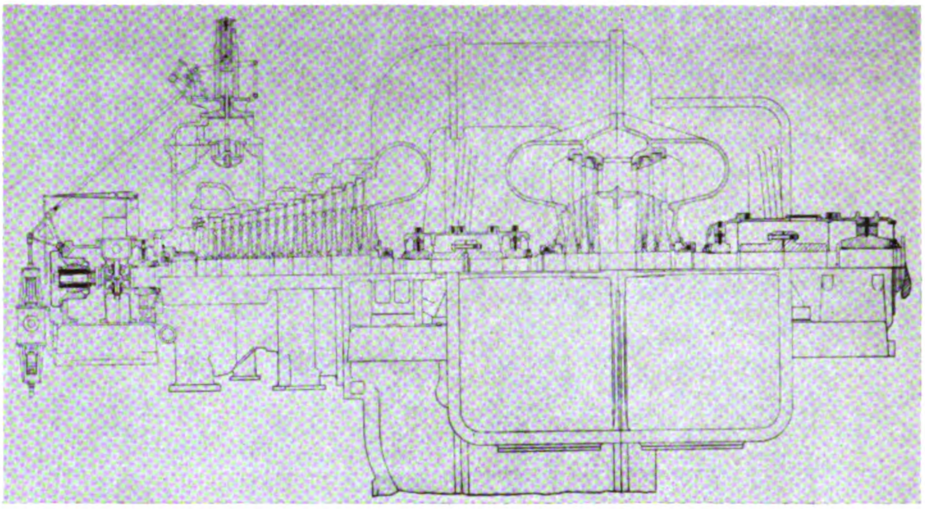

Fig. 10. 94,000-kw. 1500-r.p.m. Two-cylinder Tandem-compound Turbine for 400 lb. per sq. in. Pressure and 725 deg. F. Initial Temperature

Fig. 11 shows another large single-shaft tandem-compound turbine. It is the 160,000-kw. turbine in operation at the 14th Street Station of the New York Edison Company. This machine went into service in October, 1929, and operates at 1500 r.p.m. and 375 lb. per sq. in., 700 deg. F. and 1 in. Hg. abs. back pressure.

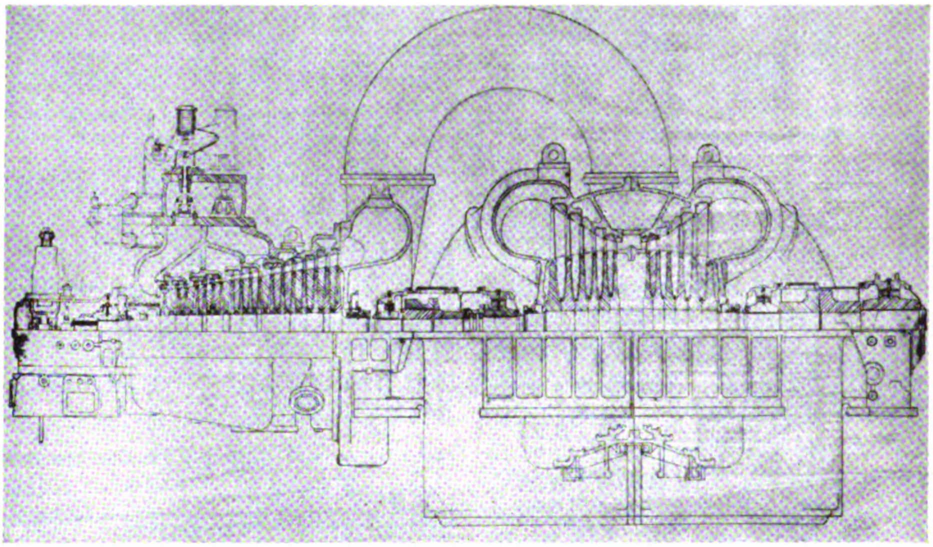

Fig. 11. 160,000-kw. 1500-r.p.m. Two-cylinder Tandem-compound Turbine for 375 lb. per sq. in. Pressure and 700 deg. F. Initial Temperature

600 Lb. Per Sq. In. Group

This group is divided into non-resuperheated and resuperheated machines, a number having been built of each kind. With 750 deg. F. initial temperature or above, the operation of 600 lb. per sq. in. turbines without resuperheat is entirely practical from the standpoint of erosion of last stage blading, although of course not so satisfactory as with some resuperheating to dry the steam.

Fig. 12 shows a single-cylinder machine built for condensing operation with 600 lb. per sq. in. steam pressure.

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(1) *Power Plant Engineering*, April 1, 1929.

Fig. 13 shows a machine for 52,500-kw. 1500-r.p.m. and 50-cycle operation, two of which are in service in the Supersina Station of the Companie Hispane America de Electricidad, Buenos Aires. The steam is resuperheated to the initial temperature between the high and low-pressure sections.

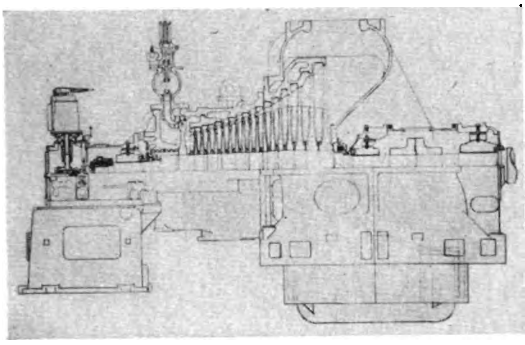


Fig. 12. 35,000 to 40,000-kw. 1800-r.p.m. Single-cylinder Turbine for 600 lb. per sq. in. Pressure and 740 deg. F. Initial Temperature

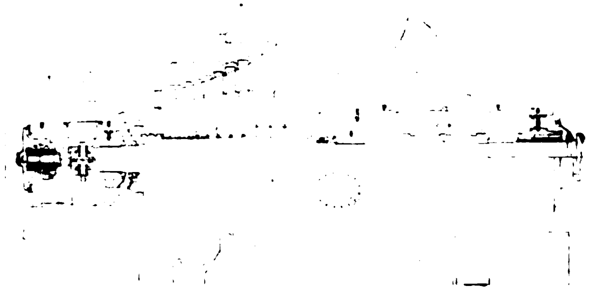


Fig. 15. One of the Two Duplicate Low-pressure Sections of the Triple Cross-compound 165,000-kw. 1800-r.p.m. Turbine for 600 lb. per sq. in. Pressure, 725 deg. F. Initial Temperature and Resuperheating to Initial Temperature

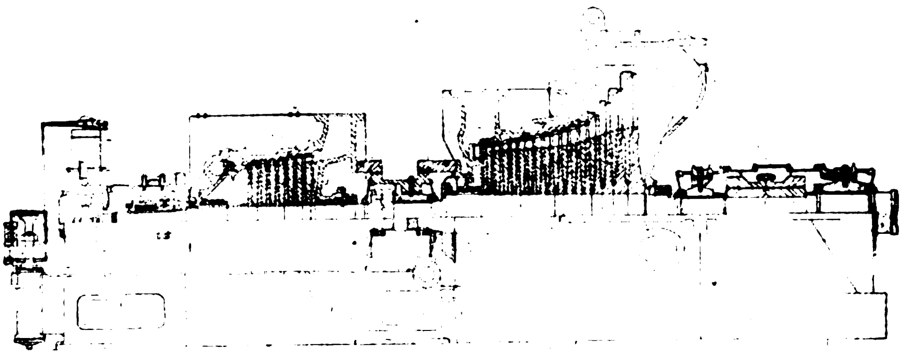


Fig. 13. 52,500-kw. 1500-r.p.m. Tandem-compound Turbine Designed for 550 lb. per sq. in. Pressure, 750 deg. F. Initial and Resuperheat Temperatures

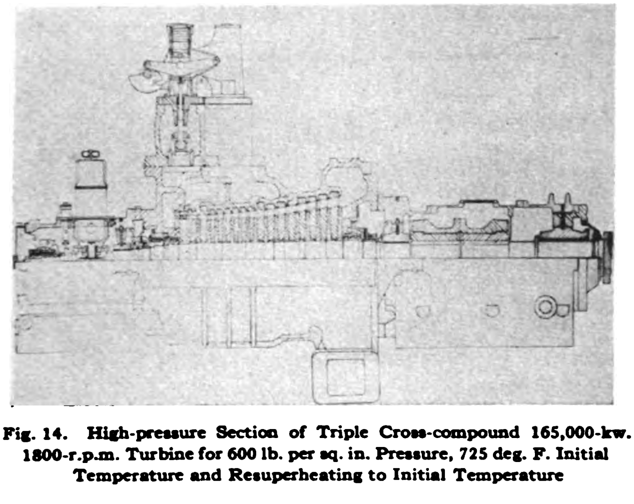


Fig. 14. High-pressure Section of Triple Cross-compound 165,000-kw. 1800-r.p.m. Turbine for 600 lb. per sq. in. Pressure, 725 deg. F. Initial Temperature and Resuperheating to Initial Temperature

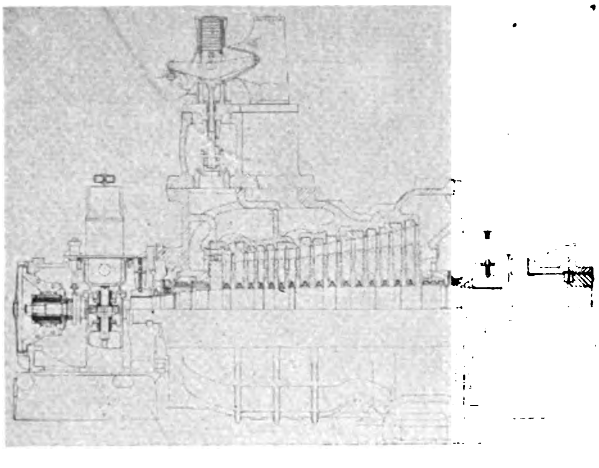


Fig. 16. High-pressure Section of Triple Cross-compound 208,000-kw. 1800-r.p.m. Turbine for 600 lb. per sq. in. Pressure, 730 deg. Initial Temperature with Steam Resuperheating to 500 deg. F. Temperature

Figs. 14 and 15 show the high and low-pressure sections of the 165,000-kw. triple cross-compound unit in service at the Philo Station of the American Gas and Electric Company at Philo (O.). This machine consists of one high-pressure turbine exhausting into two identical low-pressure turbines, each driving separate 55,000-kw. generators. The steam is resuperheated to the initial temperature between the high and low pressure sections by returning it to a special resuperheater boiler. This makes a very economical unit both from space and thermal standpoints.

Figs. 16 and 17 show the high and low-pressure sections of the 208,000-kw. triple cross-compound unit for the State Line Generating Station of the State Line Generating Company near Chicago. This machine receives steam at 600 lb. per sq. in., 730 deg. F., and it is resuperheated by live steam to 500 deg. F.

between the high and low-pressure sections. Fig. 18 shows this machine operating in the plant. This machine has vertical condensers which, although they take up somewhat more floor space, permit very favorable foundation structures and present numerous other advantages. In this particular installation (by means of very careful design and the building of a large number of model exhaust hoods and testing with air) a diffusing design of exhaust was worked out which by actual test gives a better vacuum at the last stage bucket exit than in the condensers. The usual exhaust hood gives the opposite result.

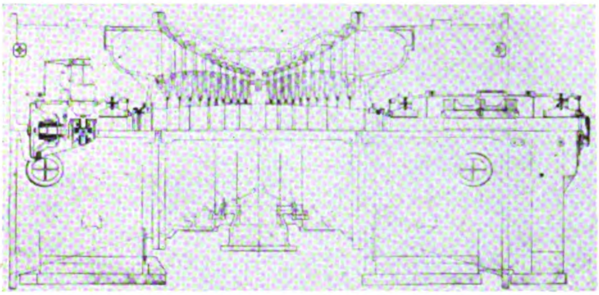


Fig. 17. One of the Two Duplicate Double-flow Low-pressure Sections of Triple Cross-compound 208,000-kw. 1800-r.p.m. Turbine for 600 lb. per sq. in. Pressure, 730 deg. F. Initial Temperature with Steam Resuperheating to 500 deg. F. Temperature

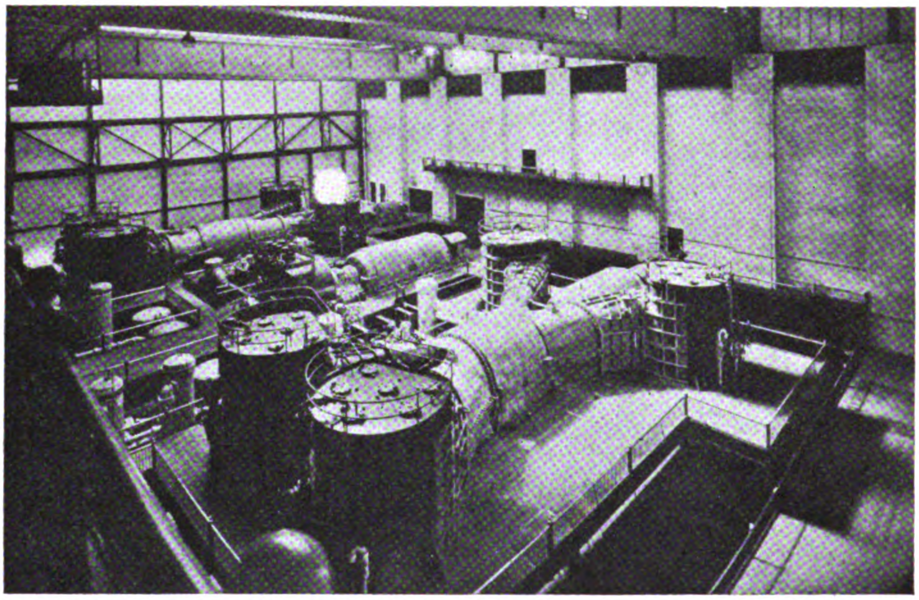


Fig. 18. View of Turbine Room of State Line Station with Triple Cross-compound Turbine Generator

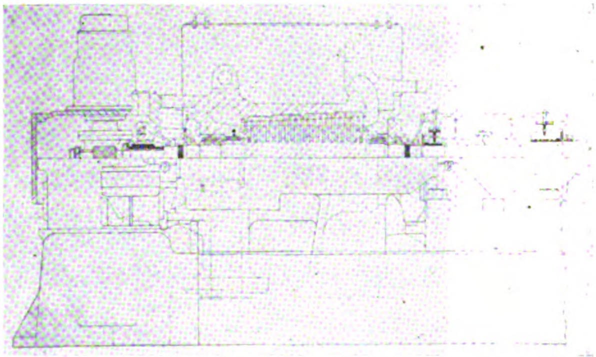


Fig. 19. 7700-kw. 3600-r.p.m. Turbine Built for 1200 lb. per sq. in. Initial Pressure, 725 deg. F. Temperature, and Back Pressure of 315 lb. per sq. in. This is a "base load" unit designed to discharge into low-pressure header of station at constant back pressure, and to run at near full load most of the time

Both the Philo and State Line triple cross-compound machines are provided with automatic devices whereby two of the machines continue in operation in case one part of the unit must be taken off the line, and provisions are made for operating the low-pressure turbines on live steam.

1200 Lb. Per Sq. In. Group

Fig. 19 shows a machine of the type purchased by the Edison Electric Illuminating Company of Boston and the Milwaukee Electric Railway and Light Company for the first 1200-lb. per sq. in installations in this country. The first Boston unit was of 2400 kw. while the second and third were of 10,000 and 12,500 kw. respectively. Two 7700-kw. units have been built

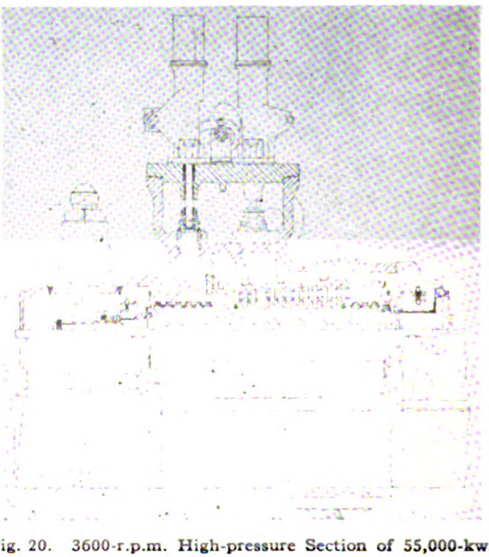


Fig. 20. 3600-r.p.m. High-pressure Section of 55,000-kw. Cross-compound Turbine for 1250 lb. per sq. in. Initial Pressure and 750 deg. F. Initial and Resuperheat Temperature

for Milwaukee and two additional duplicate units are under construction. These machines all discharge through a resuperheater into the main steam headers of a lower pressure station, their flow being regulated by the steam demands of the low-pressure units receiving steam from the header. The high-pressure section of the station then carries the "base load," so to speak, the "peak load" being carried by the low-pressure boilers. In this way the very maximum return upon the high-pressure investment is obtained, whereas the maximum economical utilization is made of the older equipment.

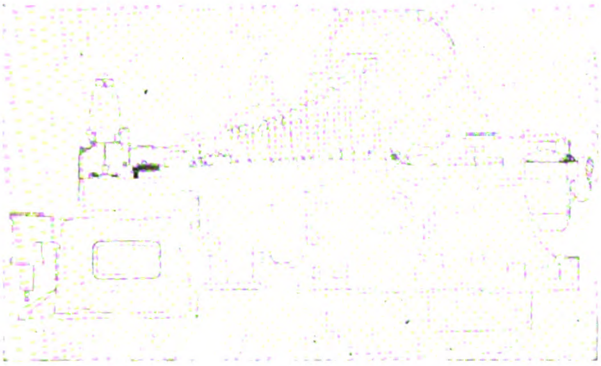


Fig. 21. 1800-r.p.m. Low-pressure Section of 55,000-kw. Cross-compound Turbine for 1250 lb. per sq. in. Initial Pressure and 750 deg. F. Initial and Resuperheat Temperature

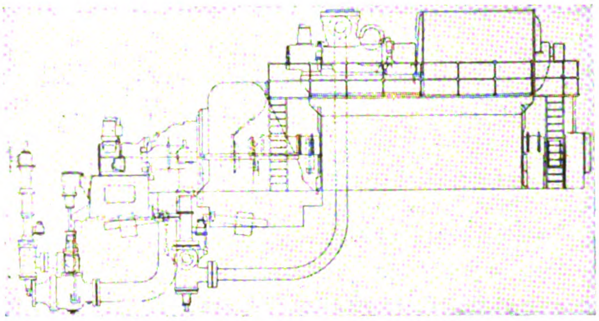


Fig. 22. View of 50,000-kw. Vertical-compound Turbine for 1250 lb. per sq. in. Pressure with Resuperheating to the Initial Temperature. Upper section runs at 3600 r.p.m.

Figs. 20 and 21 show the high and low-pressure sections respectively of the first cross-compound units to go into complete high-pressure stations. Three units of this type will be in operation in 1930: two at the Deepwater Station of the United Gas Improvement Company and the American Gas and Electric Company at Wilmington (Del.) and one at the Holland Station of the Associated Gas and Electric Company at Holland (N. J.). The steam is resuperheated to the initial temperature between the sections at from 100 to 400 lb. per sq. in. pressure, depending upon the load.

Fig. 22 shows the elevation view of a "vertical-compound" turbine. Two of this type of machine of 25,000-kw. capacity each will be in service in the South Amboy Station of the Jersey Central Power and Light Company at South Amboy (N. J.) during 1930, and two similar units of 50,000 kw. each for the Pacific Gas and Electric Company will also be in service during 1930. These machines have the high-pressure turbine and generator mounted on top of the low-pressure generator. A considerable saving of space and foundations is secured. One generator air cooler serves the two generators. The steam is resuperheated between the units to the initial temperature.

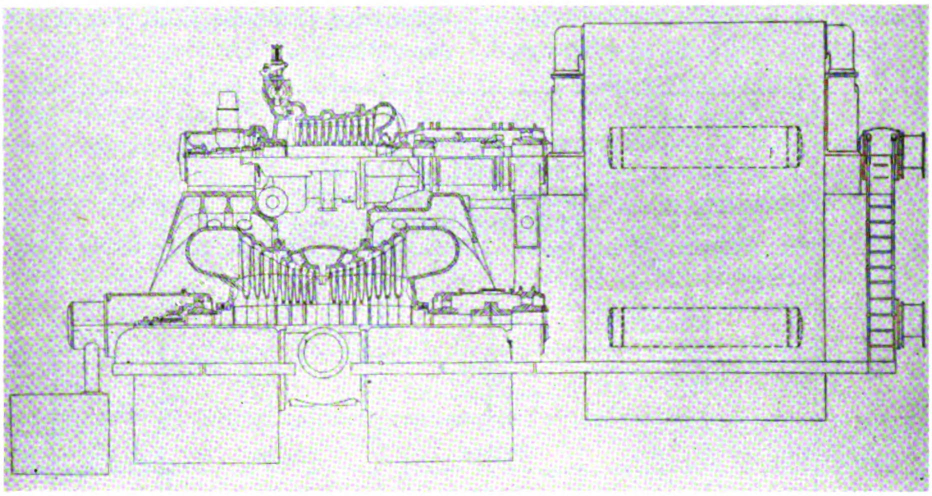


Fig. 23. 110,000-kw. Vertical-compound Turbine with Two Duplicate 1800-r.p.m. Generators. This turbine is built for 1250 lb. per sq. in. pressure and has steam resuperheating to 550 deg. F. temperature between the sections

Fig. 23 shows the 110,000-kw. vertical-compound turbine that is being built for the Ford Motor Company. This machine will have two identical generators mounted one on top of the other. The high-pressure turbine driving the upper generator will be mounted above the low-pressure element. The steam will be resuperheated by 1200 lb. per sq. in. steam between the elements. High-pressure steam resuperheating was adopted because of space limitations in the boiler and turbine rooms.

Many other turbines for 1200 lb. per sq. in. steam pressure are under consideration. This higher pressure seems to offer particular advantages as the unit sizes become larger.

(To be continued)

Economic Developments in Turbine Generators in the United States

Relation of Losses to Output—Short-circuit Ratio—Hydrogen Cooling—Ventilation and Temperature—High-voltage Generators—Future Demands

By M. A. SAVAGE

Turbine Generator Engineering Department, General Electric Company

(A paper presented at the World Power Conference, Berlin, Germany, June 16-25, 1930)

THE combination of large American power systems into ever larger units, or into the so-called super-power systems, has led to a demand for generators of a capacity far larger than would probably have occurred due only to normal growth. Records for a long period show that formerly generating units doubled in capacity every five years. During the last five years owing to these combinations individual units have tripled in capacity and, indeed, for some frequencies have quadrupled.

Fig. 1 shows graphically the increase in capacities of single-shaft units covering the period from 1920 to 1930. As will be seen, the period beyond 1925 has seen the interest in machines operating at 1200 r.p.m. decline and the same period has witnessed the rapid growth in capacities of units operating at 1800 r.p.m. This is due, in part, to the following reason: Prior to 1924 none of the American manufacturers was willing to undertake the building of units in capacities greater than 30,000 to 35,000 kw. at 1800 r.p.m. In 1925 the company with which the writer is associated, installed a 62,500-kv-a. generator operating at 1800 r.p.m. This unit clearly demonstrated that many of the previous restrictions limiting the capacities of units at this speed could be overcome, and that generators conservative in their design characteristics could be built for this and much larger capacities.

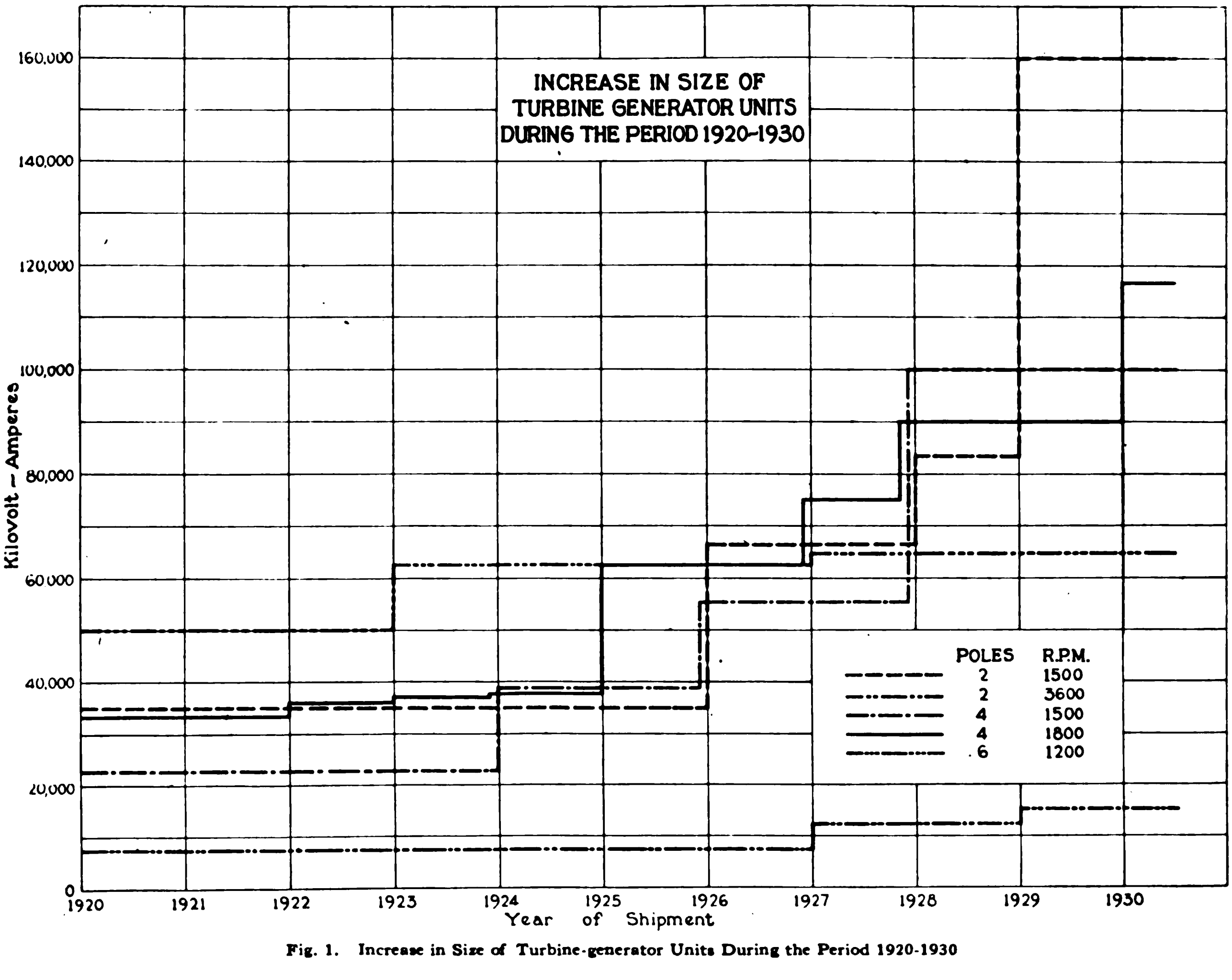


Fig. 1. Increase in Size of Turbine-generator Units During the Period 1920-1930

Table I gives data on the outstanding generators installed in the United States during the last five years. These show whether single, double, or triple-shaft units are involved. The speed, kv-a. rating, and voltage are given for each generator.

In dealing with the rapid growth of the power demand in America, it will be the writer's endeavor, first, to discuss briefly some of the factors which have brought about this demand. Second, to show how the demand has been met by the manufacturer and to give, in a nontechnical way, some of the design features which have made such large machines possible. Third, to describe briefly, with the aid of photographs, some of the outstanding machines built and installed, during the period under discussion.

The principal reason for the so-called Super Power Systems lies in the economies which such combinations bring; both in regard to generation and distribution of power. In the earlier systems the individual generator was installed as part of a rather isolated system. Its size, therefore, was dictated largely by its percentage of the connected load. With the combining of these isolated systems into larger and larger systems all restrictions as to the sizes of units, from the standpoint of system capacity, have been removed and the demand has been dictated largely by the economies of the situation. This has led to the interest in the so-called base load stations. These stations are designed primarily to operate on the highest load factor which the system will permit. Every reasonable expenditure is allowed for in the design of such stations which will show increased economy of operation. In order, therefore, to keep the capital expenditure to as low a figure as possible it has been highly desirable to install units of large capacity. Not only do such units show a lower cost per kw. installed in the generating apparatus, but the cost of the switchgear and other power controlling apparatus is reduced.

In meeting the demand for generators in present sizes the manufacturer is dependent, to a large extent, on the source of raw materials in sizes and quality sufficient to meet the demand and finally upon transportation facilities to get the finished product to its destination. The limitations imposed by both of these factors has in some instances resulted in exercising considerable ingenuity by the manufacturer in adapting the materials and transportation facilities available to the production of units of much greater capacity than those facilities would permit under previous designs. This is illustrated in the two-part frame designs of the stator and the three-piece rotor designs of the rotor, both of which will be touched on later.

The manufacturer has met this demand for large units:

(1). By reducing the losses so that more kilowatts can be carried with the same weight of material.

(2). By better systems of ventilation so that the heat from the remaining losses is more efficiently removed.

(3). By employing materials with better physical properties and thereby greatly reducing the weights of the parts.

(4). By a close coöperation between the engineering and manufacturing departments so that the finished designs lend themselves to a more efficient manufacture of the article.

TABLE I

Year of Shipment	Type of Generator	Generator Kilowatts	Rating Kilovolt-amperes	Power-factor	R.P.M.	Freq.	Volts
1925	Single Shaft	50,000	62,500	0.8	1800	60	13,800
1926	Single Shaft	60,000	60,000	1.0	1500	25	11,400
1926	Single Shaft	60,000	66,667	0.9	1500	25	12,000
1926	Double Shaft	75,000	55,000	0.85	1200	60	12,000
			33,235	0.85	1800	60	12,000
1927	Single Shaft	60,000	75,000	0.8	1800	60	14,000
1927	Double Shaft	88,000	64,700	0.85	1200	60	12,000
			38,825	0.85	1800	60	12,000
1928	Single Shaft	52,500	61,765	0.85	1800	60	22,000
1928	Single Shaft	75,000	83,333	0.9	1500	25	12,000
1928	Single Shaft	90,000	100,000	0.9	1500	50	16,500
1928	Triple Shaft	159,000	3—62,353	0.85	1800	60	11,000
1928	Triple Shaft	200,000	1—89,411	0.85	1800	60	22,000
			2—72,941	0.85	1800	60	22,000
1929	Single Shaft	75,000	83,333	0.9	1800	60	13,800
1929	Single Shaft	160,000	160,000	1.0	1500	25	11,400
1930	Single Shaft	75,000	93,750	0.8	1500	25	12,000
1930	Single Shaft	80,000	100,000	0.8	1800	60	12,000
1930	Single Shaft	90,000	100,000	0.9	1500	50	16,500
Under Construction	Single Shaft	75,000	93,750	0.8	1800	60	13,200
	Single Shaft	105,000	116,667	0.9	1800	60	22,000
1930	Double Shaft	110,000	1—62,025	0.79	1800	60	13,800
			1—62,886	0.97	1800	60	13,800

Losses and Their Relation to Output

When viewed from the present day standards, generators built as late as 1924 were rather inefficient machines. They were subject to rather large load losses and, what was still more serious, these losses were often concentrated into such restricted areas as in some instances to seriously affect the life of the machines. As early as 1921 the writer began to realize the fact that if the demand for larger generating units was to be met, a more complete knowledge of the source and magnitude of such losses was necessary. The difficulty of obtaining accurate determinations on the units of the size even then under construction was such that it would require years to accumulate the necessary data, and this would seriously retard the building of larger machines. It was finally decided to construct two little generators which would duplicate, in all essential details, the larger machines. These machines were so designed that rapid and inexpensive changes could be made in their construction and the effect upon the losses of the machine tested out. In this manner data were obtained in a relatively short space of time which under ordinary circumstances would have required years to accumulate. It is interesting to record that these little machines are still in use. The investigations carried out on these developmental machines led to the general adoption of non-magnetic steels for the so-called inactive parts at the heads of the machines, such as clamping flanges, fingers, etc.

As the result of the improvement effected by the changes mentioned above, as well as the better ventilation mentioned elsewhere, the efficiency of these units was increased from 96.5, or 97 per cent, to 98 per cent; and in the very largest units to something like 98.5 per cent. This increase in efficiency is of far-reaching effect because if the 100,000-kv-a. generator, described elsewhere in this article, had been built with the losses of the earlier machines it would have required some 1600 kw. to ventilate it, instead of only some 400 kw. which was actually required. This means that its ventilation would have been an extremely difficult matter and would probably have resulted in an actual reduction in the capacity of the unit.

Machines of greater rating and higher efficiencies are possible when magnetic materials of the best quality are employed. In utilizing steels of high silicon content it is important that magnetic densities be carefully scrutinized in order to obtain low losses. Any reduction in the fixed losses in the generator is a two-fold benefit because less air is required to provide the proper ventilation with lower power loss chargeable to the ventilation. For each kw. saved in these losses approximately 0.25 kw. less power is required to ventilate such a machine. This fact is of great importance in machines designed for operation with a poor load-factor.

Short-circuit Ratio and Reliability

The ratio of the field ampere-turns at no-load normal voltage to field ampere-turns with armature short circuited at normal current is known as short-circuit ratio. There is a wide divergence of opinion among designers as to what is the proper short-circuit ratio. In Europe the practice has been to design machines with short-circuit ratios as low as 0.5. In America the short-circuit ratios have been, in general, kept as high as 0.9 and unity. High armature current or low short-circuit ratios result in an increase in the so-called load losses, at the same time they reduce other losses and result in a cheaper machine. The character of the load should have some bearing on this point. If the machine is intended for operation on a system where the load-factor is poor and where it is called upon to carry its rating for only relatively short periods, which then become in the nature of an overload, lower short-circuit-ratio machines might advantageously be used as such machines will, in general, show a higher efficiency at the lighter loads than will machines of high short-circuit ratio.

In America nearly all of the large generators have been built for operation in the so-called base load stations. These stations are usually located from a standpoint of greatest accessibility to the two essentials, coal or oil, and water. Their location, therefore, may be at a considerable distance from the center of the load distribution. Such machines will, in general, provide more reliable service if designed with a high short-circuit ratio.

In building machines of enormous capacities the desirability of having machines of great reliability cannot be over-emphasized. The design factors for which the modern designer must strive, in the order of their importance, should be reliability, efficiency and cost. If these factors are followed through to a logical conclusion the size of the units for a given output becomes greater than what would obtain if the machines were designed to get the greatest output compatible with their temperature guarantee. The economic loss involved in the shut down of one of these large units is so great that an increased first cost is fully justified if such increase results in greater reliability and higher efficiencies.

Hydrogen Cooling

Because of high rotational speed, the frictional loss, commonly called windage loss, becomes a serious factor in the efficiency of this type of unit. The problem of operating this class of apparatus in a medium of low density has claimed the attention of engineers for years. With the advent of the closed system of ventilation, and surface coolers for extracting the heat from the cooling medium, the problem of the utilization of a gas lighter than air received a marked impetus. Hydrogen, owing to its many favorable characteristics, has become accepted as the most desirable gas for this use. Hydrogen cooling is perfectly practicable and its adoption will mark the next big step forward in the increase in efficiency of these large units.

The manufacturing company with which the writer is associated built and operated, for a considerable period of time, a 6250-kv-a. 3600-r.p.m. generator employing hydrogen gas as the cooling medium. The laws governing the leakage around the shaft seals at the two ends of the machine have been carefully determined, as have also the laws governing the relative loading of the machine in air and hydrogen. These data indicate that large generators can be built with efficiencies at rated load 0.6 per cent higher when operating in hydrogen, and that the active magnetic material can be reduced some 25 per cent for the same kw. output. Or, expressing this in another way, machines of 25 per cent greater output will ultimately be possible when the limit in capacity is reached in air-cooled generators.

Since hydrogen cooling results in a reduction in the so-called fixed losses it becomes of increasing importance in those machines intended for operation on rather poor load-factors. There are a number of synchronous condensers in operation in America which are successfully employing hydrogen cooling. These have operated to the complete satisfaction of the purchaser. Its adoption in large generators will come at the time when the invested capital shows a greater return than the same capital invested in other parts of the power station.

Ventilation

Prior to 1925 the 30,000-kw. 1800-r.p.m. machines were ventilated by carrying part of the air to a central compartment at the back of the machine. From here it flowed radially inward to the air gap, and then axially along the air gap, until it joined the main volumes of air which had entered at the two ends of the machine. It then flowed radially outward. This division of the ventilating paths was adequate and effective in machines of a certain length. When, however, it became necessary to build machines of greater capacity it was realized that such a division would entail pressure drops far beyond what would be considered good practice. The natural development, therefore, was to arrange the core length into a larger number of multiple paths. Such an arrangement results in an increase in velocity in the radial air ducts, at the same time it reduces the air gap velocity. With a higher velocity in these air ducts it became apparent that a real gain in efficiency could be made by improving the entrance conditions to these air ducts. As it enters the air gap the air has a direction parallel with the shaft. As soon as it passes within the restraining walls, formed by the armature and rotor surfaces, it is immediately acted upon by the rotating surface of the rotor and its direction quickly changed from an axial to a tangential flow. By means of specially designed vanes, which were inserted from the back of the punchings directly into the air gap, a complete study was made of the direction and velocities of the air in the air gap on actual machines under a wide variety of ventilating arrangements. These experiments showed some rather surprising results as regards the resistance imposed on the air in passing from a tangential to a radial direction in entering the air ducts.

In order to obtain data, in regard to the above feature, sections of armature punchings were made up. These were tested in an air tunnel at pressures and velocities corresponding with those in the actual machine. A vast amount of data were collected on a large number of entrance ducts of many shapes. Some of these data showed that variations as great as 300 per cent were possible in the amount of air put through a given shape of air duct, and in a few cases it was even found that the air actually flowed into the air gap instead of outward as would be expected.

Fig. 2 shows the ventilation tests on a 62,500-kv-a. generator, at 1800 r.p.m., built in America. This machine embodied many of the improvements in ventilation which the tests of machines, previously described, had shown to be sound. The outstanding fact which these tests brought out was that as far as ventilation was concerned machines of any length could be built and if properly designed they could be as well ventilated as the shorter machines. This conclusion was of far reaching importance as it removed one of the factors which up to this time had more than any other impeded the progress in size of generating units. A second conclusion, of equal importance, was that if properly designed a machine of this rating could be built with losses, chargeable to windage, no greater than those of the 30,000-kw. generators previously referred to. This machine employed external blowers instead of fans attached to the rotor, and this method of supplying the necessary ventilating air has become general on all of the larger units. Four high-speed high-efficiency blowers are usually used. Such an installation provides a very flexible and economic operating arrangement for, at the light loads, one or two blowers may be shut down with a consequent saving in power.

Temperatures

Many of the large single-shaft turbine generators built in America to date have temperature rises in the stator windings, as measured by embedded temperature detectors, of 45 deg. to 50 deg. C., and rises of 60 deg. to 70 deg. C., by rise in resistance, in the rotor windings. When viewed from the standpoint of the temperatures allowed for Class B insulation, by the A.I.E.E., such machines seem very conservative.

After a long experience the writer is of the opinion that such temperatures are not too conservative when dealing with machines requiring core lengths such as are built today.

Nearly all of the manufacturers employing Class B insulation are forced for the want of something better to make use of mica bonded by some varnish or sticker. Such insulations are extremely tough and strong in compression, but have the strength only of the bonding material in tension. It is extremely important, therefore, to minimize as far as possible the relative movement between copper and iron. The greater the temperature difference between the copper and iron the greater will be this relative movement. The logical conclusion is, therefore, that the longer the generator the more conservative its temperatures should be. At the same time a great deal of effort is made to devise constructions which will minimize these relative movements and a vast amount of work is being done to improve the bonding materials.

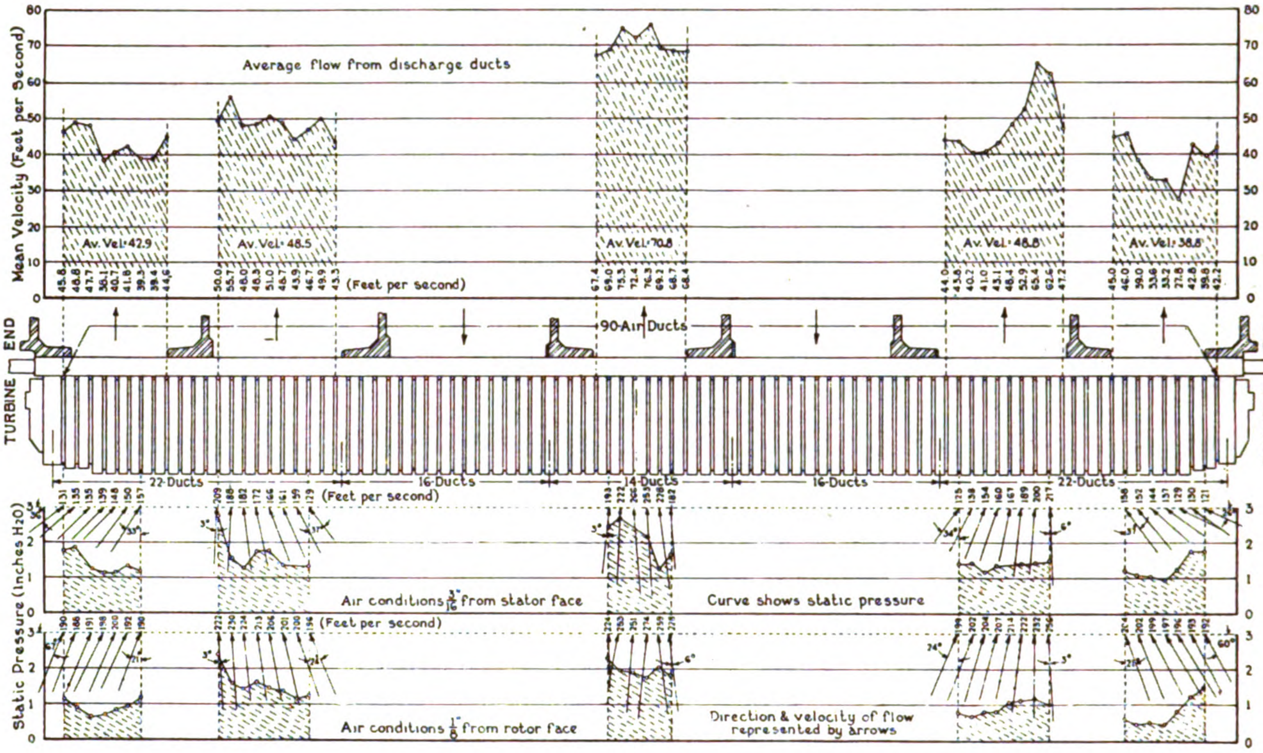


Fig. 2. Ventilation Tests on 62,500-kv-a. 1800-r.p.m. 13,800-volt Generator. Longitudinal cross-section of stator core, showing ingoing and outgoing sections; stator pressures, and relative directions and velocities of flow

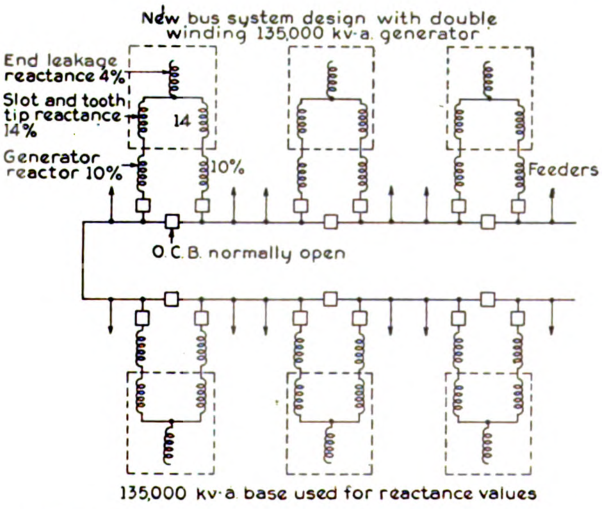

New bus system design with double winding 135,000 kv-a. generator
End leakage reactance 4%
Slot and tooth tip reactance 14%
14
Generator reactor 10%
10%
Feeders
O.C.B. normally open
135,000 kv-a base used for reactance values

Fig. 3. Typical Electrical Circuit Arrangement of Double-winding Generator Connected to a Ring Bus

High-voltage Generators

Within the past few years interest has developed both in the United States and abroad in generators built for voltages higher than those which had been standard, namely, 13,200 to 14,000 volts. This trend has been for entirely different reasons. In England voltages as high as 33,000 have been advocated and one machine has been built at this voltage. The justification for such a voltage lies solely in the elimination of the step-up transformers. In the United States the trend toward higher voltages has been brought about largely by the increase in generator capacities, and in an effort to minimize switching difficulties.

The distribution areas being so widely scattered in the United States, most of the power from the large stations today is sent out at potentials much higher than it would be possible to build generators for with our present knowledge. No attempt, therefore, has been made to adapt the generator voltage to the transmission potential. In those cases where power is distributed at various potentials, say 33,000, 66,000, and 132,000 volts, it usually works out cheaper to use step-up transformers for all three voltages than to wind the generator for 33 kv. and use step-up transformers for the two remaining voltages.

Still another difficulty in the design of generators for transmission potentials lies in the hazard involved in surge potentials to which such transmission lines, especially those of moderate potentials, are subjected. The class of insulation which it is desirable to use in the generator is not as well suited for resisting surge potentials as other classes which are totally unsuited mechanically to large generators.

All of these considerations have worked together to confine the building of large generators to the potentials which are most economical in station switching and bus bar equipment.

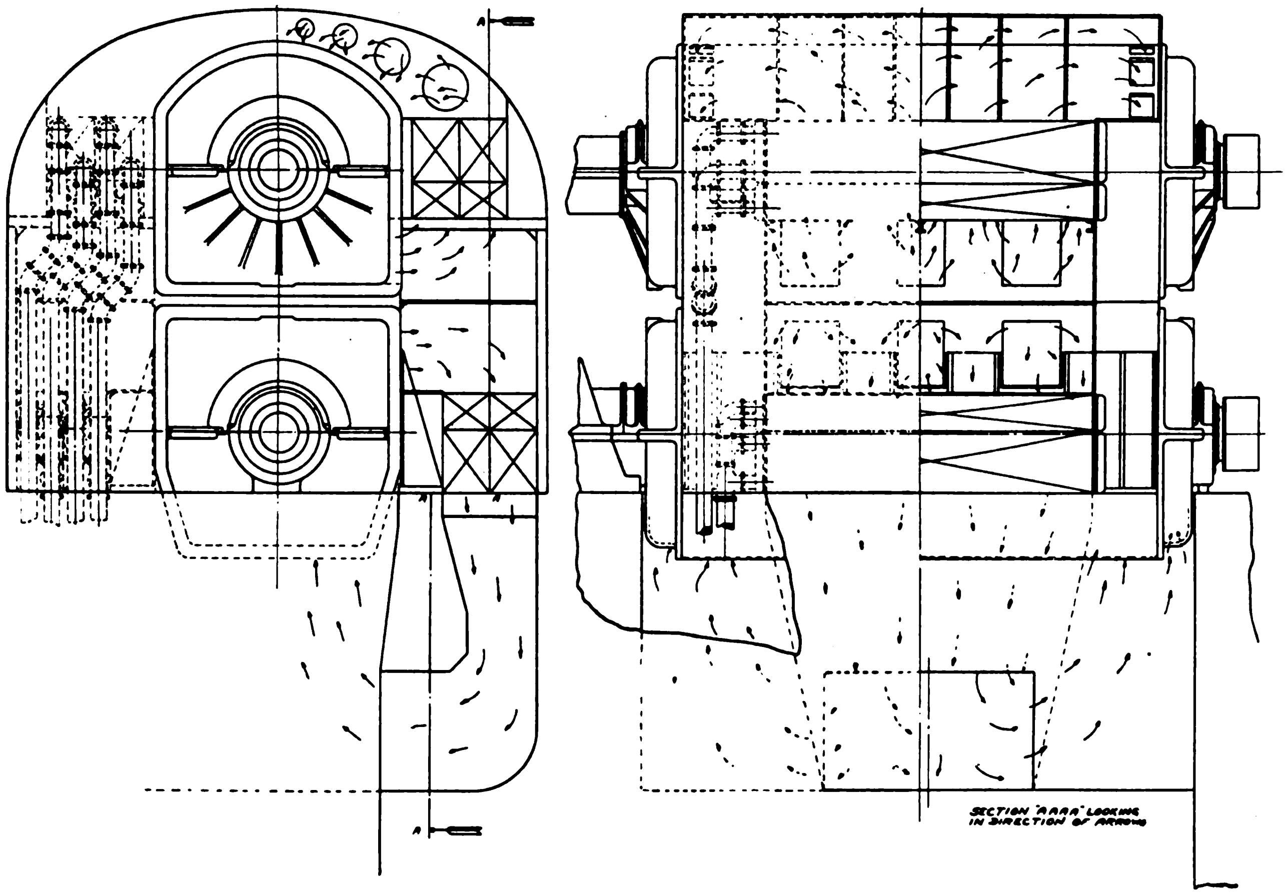


Fig. 4. Ventilation Arrangement for 110,000-kw. 60-cycle 1800-r.p.m. 13,800-volt Vertical-compound Set

The introduction of the so-called double winding in large generators has retarded to some extent the trend to higher voltages in these machines. The double winding consists, briefly, in dividing the coils, which make up the three phases, into two circuits and arranging them in the correct slot relationship in such a manner that they will be in phase and voltage agreement with high self induction with respect to each other.

Each winding, therefore, will carry half the output of the machine. If these independent windings are tied to separate buses, the switching problem is greatly minimized as the current to be handled is just half of what would be the case in an ordinary generator, or it would be the same as if the generator were wound for 27,600 instead of 13,800 volts.

Fig. 3 shows a typical wiring diagram for such generators connected to a ring bus.

Rotor

There are three distinct types of rotors built by the leading manufacturers of today. The first is the solid rotor type in which the rotor is made up of one or more forgings. The second is the plate rotor type in which a series of plates or disks is bolted together to form the rotor body structure. The third is the through shaft dovetail punching type, in which the shaft is a solid forging which has been slotted and dovetailed to receive the punchings which carry the rotor coils.

Each one of these types has its advocates, and each type has some inherent advantages which the others do not possess. From time to time articles appear in the technical press of the world in which some writer attempts to point out the superiority of one type over another. Such articles are useful as they tend to stimulate thought which leads to progress. The writer has no intention of joining in such a controversy. His first-hand knowledge would allow him to speak with some authority on only two of the three types.

Suffice it to say that the manufacturing company with which the writer is associated has brought its steel forge type of rotor to its present state of perfection only after the most careful and painstaking research. Over one thousand of these rotors have been built and put into service; and not one of them has failed due to imperfections in the rotor forging. This is an enviable record and is a most convincing argument that this type of rotor is thoroughly reliable if properly built.

In the design of the 62,500-kv-a. generator, described earlier in this article, the rotor diameter was the same as those of the 30,000-kv-a. previously built. The centrifugal stresses, therefore, were no greater than had been previously encountered. With further increases in the capacity of the units the diameters have been increased. Many of the stresses, however, on these rotors of greater diameter have not increased due to the fact that the copper space has not been increased in proportion to the increased diameter. The body stresses have increased somewhat but, to offset this, alloy steels are being employed which give a higher factor of safety than many of the smaller units enjoyed.

In the largest sizes the rotors are made of three pieces, a central cylinder, and two stub ends which carry the journals. There are a number of reasons for this construction; it reduces the size of the individual piece, and therefore the cost. It allows the main cylinder to be worked to its inner bore as well as to its outside diameter, insuring better material, and it allows a more thorough inspection to be made of the forgings.

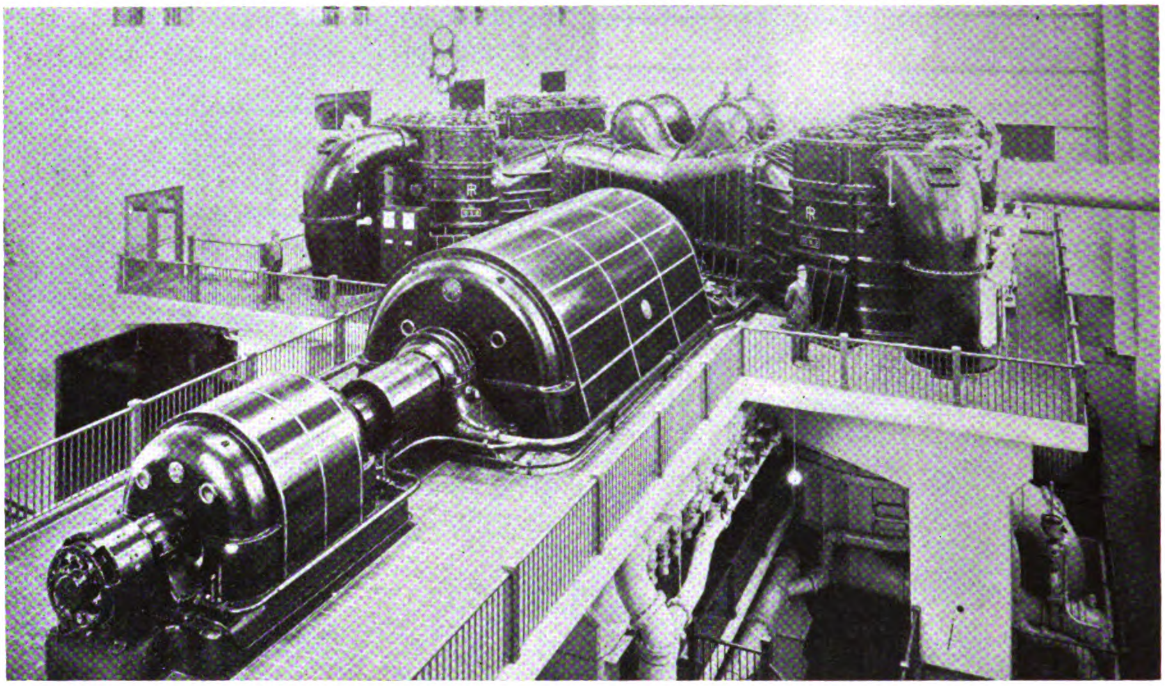


Fig. 5. 100,000-kv-a. 1500-r.p.m. 16,500-volt 50-cycle Generator with 4000-kw. Auxiliary Generator and 94,000-kw. Tandem-compound Turbine. Long Beach Station of Southern California Edison Company

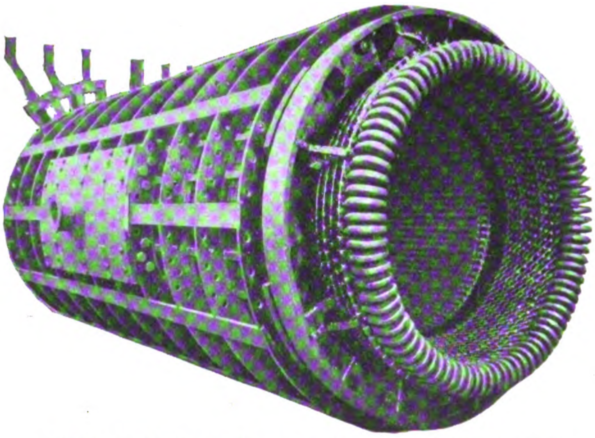


Fig. 6. Inside Stator Structure Complete with Winding and Supports. Turbine end of a 100,000-kv-a. 1500-r.p.m. 16,500-volt 50-cycle generator

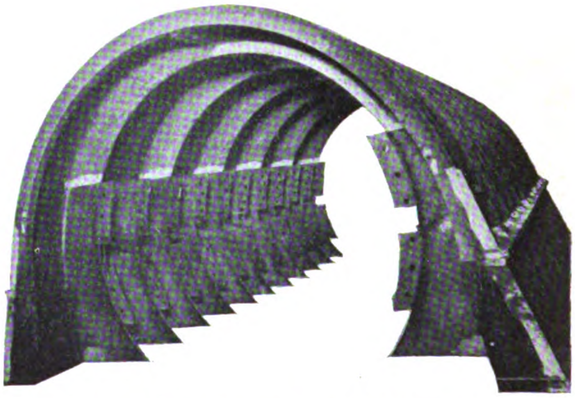


Fig. 7. Outer Stator Structure of a 100,000-kv-a. 1500-r.p.m. 16,500-volt 50-cycle Generator, Shipped Separately and Bolted to Inside Structure at Destination

Vertical Compound Generators

Owing to the value of the floor space in a modern power station, many plans have from time to time been brought forward to increase the installed capacity in a given ground area. One of the most recent to attract the attention of the engineers is the use of the so-called vertical compound units. Five units designed on this principle are now under construction in the United States for three different power companies. The largest of these is rated at 110,000 kw. 0.9 p-f. 13,800 volts; and consists of two equal generators rated 55,000 kw. 0.9 p-f. 61,111 kv-a. The frame of the lower generator forms the base of the upper generator, which is coupled to the high-pressure element of a steam turbine designed to operate at 1200-lb. gauge pressure. Each of the generators operate at 1800 r.p.m.

The design of this unit is unique in many details. Fig. 4 shows the ventilating arrangement of the unit. Each generator has its own coolers which are arranged in a specially designed ventilating housing and which is common to both machines. Instead of the usual base type pillow block, which is common with generators of this size, the bearings are carried in, and form a part of, the shield structure Thus each generator becomes a self contained unit.

The movement of air in each machine is accomplished by fans attached to its own rotor.

100,000-kv-a. 16,500-volt 1500-r.p.m. Generator

Fig. 5 shows the 100,000-kv-a. 16,500-volt 1500-r.p.m. generator installed in the Long Beach Station of the Southern California Edison Co. The building of this generator brought up a number of problems, largely mechanical, which are typical of the trend in modern design. When the order for this unit was placed it was contemplated that the machine would be assembled at its destination. The difficulty of transporting all of the component parts of a machine of this size 3000 miles across the country, and assembling them under conditions which are anything but ideal, made it seem desirable to design the machine so that it could be shipped completely assembled and wound. Weights were carefully scrutinized and it was finally decided that if the frame weight could be kept to 25,000 lb. the problem could be solved. Such a weight was out of the question on the basis of any past design. A design was finally worked out whereby both the weight and dimensional requirements for shipment could be met. The frame was divided into two parts, an inner member or cage, see Fig. 6; and an outer structure, see Fig. 7. The inner member consists of annular plates held on the outside by narrow steel slats, and on the inside by the core dovetail ribs which were let into the plate. This structure is intended largely as an assembling jig for the punchings. After the punchings were assembled and clamped, the ribs and outside slats were welded in place. The whole structure thus became a rigid member which could be handled.

The outer structure consists of a number of foot plates spaced so as to coincide with the circular plates of the inner structure to which they are securely bolted when assembled on the base. These footplates are welded to side plates which form an enclosure and add stiffness horizontally. Over this structure, when assembled is placed a steel cover. This cover plate also carries radial supporting plates which form the various air chambers.

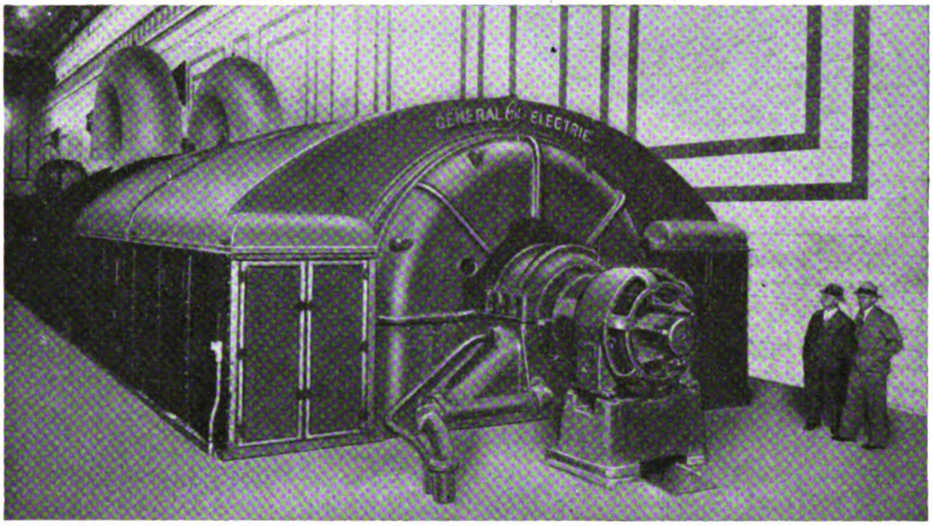


Fig. 8. 160,000-kw. 1500-r.p.m. 11,400-volt 25-cycle Turbine-generator in the East River Station of the New York Edison Company

160,000-kw. 1500-r.p.m. 25-cycle Generator

The use of 25-cycle power has practically given way to 60 cycles in this country except in certain districts, notably around Niagara Falls and the metropolitan area of New York. While these latter places are considering the problem of changing over to 60 cycles, they still require large blocks of 25-cycle power.

Fig. 8 shows the 160,000-kw. 25-cycle 1500-r.p.m. generator for the New York Edison Company as installed in the 14th Street Station. The building of a generator of this enormous capacity involved a number of new problems. The frame (see Fig. 9) is made entirely of steel plate welded and represents the most approved practice in this construction. The non-magnetic steel clamping flanges at the two ends of the stator and the cast iron end shields are the only castings in the generator proper. The employment of steel plate and the application of the art of welding has resulted in marked reduction in weight and at the same time resulted in a much stronger structure than was possible with the fabricated cast-iron structure formerly built. As an example of this weight reduction, a recent design of frame on a 75,000-kv-a. generator showed practically the same weight as the frame of a 37,500-kv-a. generator of an earlier design in which castings were employed.

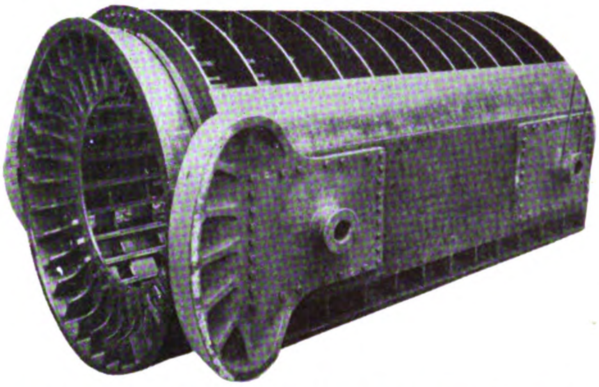


Fig. 9. 160,000-kw. 1500-r.p.m. 11,400-volt 25-cycle Generator, Showing Stator Frame and the Special Trunnion for Changing from Vertical to Horizontal Position After Stacking Core

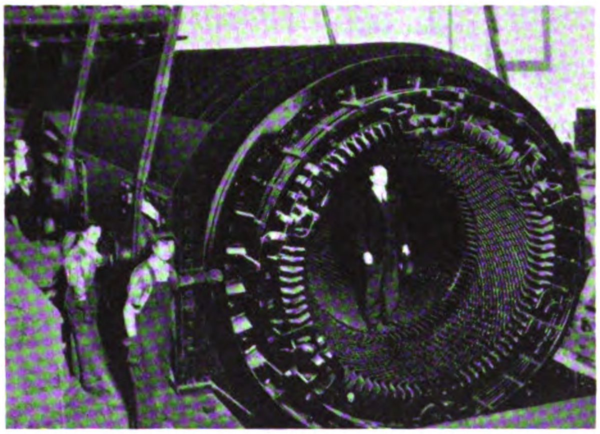


Fig. 10. Wound Stationary Armature for 160,000-kw. 1500-r.p.m. 25-cycle 11,400-volt Turbine Generator

Owing to the physical dimensions of the 160,000-kw. generator and enormous weight, the stator core and winding of this unit were assembled at its destination. Specially designed trunnions were necessary in order that the frame, after it had received its load of half a million pounds of laminations, could be turned from a vertical to a horizontal position on its base. See Fig. 9.

Fig. 10 shows the wound stator after it has been lifted on to its base. Over the frame seen here the ventilating housing, shown in Fig. 8, is assembled.

The winding of this generator is of the transposed bar type with two bars assembled in each slot. This is the first machine to make use of the two-circuit or so-called double winding. Each winding is connected delta and, to eliminate the objectionable harmonic currents in the delta, the pitch of the coils was made 66⅔ per cent. Each winding is connected to a separate bus section and these busses have no tie between them other than the generator windings. In case of a short circuit on one bus, the generator windings aid in reducing the flow of current along the bus.

Fig. 11 shows a view of the rotor for the 160,000-kw. unit. The retaining rings are not assembled. The end construction of the rotor can be seen. The rotor forgings are made in three pieces, a body and two stub ends. The body portion alone weighed 228,000 lb., and is the largest single forging ever made by the steel mills. This forging involved the use of a billet weighing 465,000 lb.

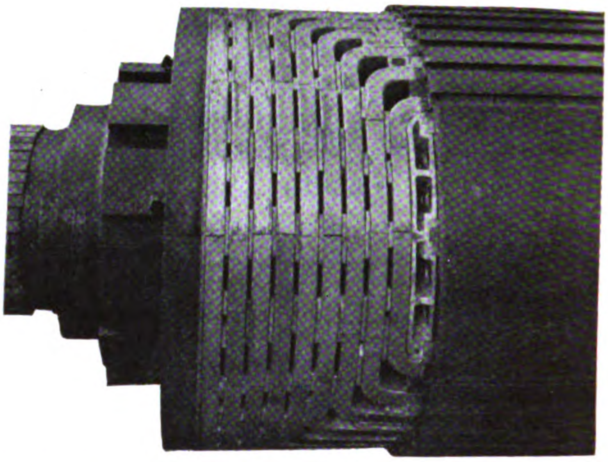


Fig. 11. Wound Rotor Without End Retaining Rings, Showing Aluminum Saddles and Blocking in End Windings of a 160,000-kw. 1500-r.p.m. 11,400-volt 25-cycle Generator. Length overall, 39 ft. 7 in.; weight complete, 290,000 lb.

Future Demand in Turbine Generators

As far as the writer knows there is not contemplated in America a single-shaft unit greater in capacity than the 160,000-kw. generator just described. Active research however is being carried out to obtain materials, especially those used in the rotors, of better physical properties. For each increase of 10 per cent in the diameter, an increase of approximately 33 per cent is secured in the rating of such machines. The employment of better materials, therefore, offers possibilities of building machines of even greater capacity than those discussed. A great amount of work is being done in all the countries in an effort to utilize steam in the steam turbine at pressures and temperatures higher than is used today. Such turbines will undoubtedly show economies in sizes greater than those now being built and it is confidently believed that when such a demand arises generators can be built in sizes far beyond their present capacities.

Welded Steel Buildings and Bridges in the United States

Noteworthy Examples—Arc-welding Applications to Reinforce Corroded or Overstressed Structural Members—Cities Incorporating Welding in Building Codes—Permissible Stresses

By **FRANK P. McKIBBEN**
Consulting Engineer for the General Electric Company

(A paper presented at the World Power Conference, Berlin, Germany, June 16-25, 1930)

THERE are in the United States over one hundred bridges and buildings in which welding has been used wholly or partially for connecting together the members constituting the steel framework.

Among the most notable examples is the eleven-story Hotel Homestead, Hot Springs (Va.), which is the tallest welded building (180 ft. high) thus far attempted. All the steel, both in the shop and at the building site, was welded. Another important structure is the steam power plant at Hotel Chalfont, Atlantic City (N. J.), which is 150 ft. high and has all the field connections of beams and girders to columns, all column splices, and all important connections of beams to girders welded. Less important connections of secondary beams to girders were bolted in the field in accordance with the usual practice in Atlantic City. Except for a few very heavy plate girders which were fabricated in another shop than that in which the shop welding was performed, practically all the shop work of this structure was welded. At present the welded building having the largest steel tonnage is the welded shop of the General Electric Company at West Philadelphia (Pa.), wherein 987 tons of steel were used with all shop and field work welded except in a few unimportant connections where bolts were used.

Another interesting application of welding and one in which it has a most promising field lies in the strengthening of existing steel bridges or shop buildings where corroded or overstressed members are renewed or reinforced.

Some outstanding examples of this bridge strengthening are: Reinforcing by arc welding an old railroad bridge over the Missouri River at Leavenworth (Kan.), consisting of one 400-ft. draw span and two 330-ft. fixed spans. In this work 325,000 lb. of structural steel were added; 7500 lineal feet of welds and 2,000 lb. of welding wire were used during the reinforcement which was accomplished between Feb. 28, and April 28, 1928, without interrupting normal railway traffic on the bridge. An old single-track Pennsylvania Railroad Bridge over the Susquehanna River at Havre de Grace (Md.) had an additional floor system welded into the old trusses above the existing floor to convert the structure into a double-deck highway bridge for heavy automobile traffic. The bridge, consisting of several spans, is approximately 3,000 ft. in length; 1500 tons of steel were added by welding and no rivets were used. A Pennsylvania Railroad Bridge near Pittsburgh (Pa.) has three spans of pin-connected trusses in which several of the diagonal truss members each of which, consisting of two eye bars, had one bar too long so that the dead and live load stresses were borne largely by one bar. To shorten each long bar, a pair of turnbuckles were added to it by welding and then a short portion of the main bar was removed by the oxy-acetylene torch, the turnbuckles tightened and shortened so that the long bar then carried its proportion of the stress.

In this latter case the welded portion replaced the original bar and could be adjusted to carry stress. But in many cases of strengthening old structures, such as girders, truss members, or columns, the transference of a portion of the dead-load stress to the new reinforcement is not easily secured. Consider a plate-girder tension flange consisting of two angles to which is to be welded a plate to increase the flange area in order to reduce the dead-load unit tension in the flange. If the plate be welded cold, the dead-load stress remains carried by the angles only. To transfer stress to the plate, the girder must be temporarily supported and raised during the welding or else the plate must be pre-heated to a proper temperature so that when cool it will carry its full share of the dead-load stress.

(1). *How many degrees, D, increase above air temperature are required to cause a unit stress of S lb. per sq. in. in the added steel?*

Change in length of added steel due to stress $= \frac{SL}{E}$

Change in length of added steel due to heat $= DCL$

Equating these and solving for D, $D = \frac{S}{EC}$

where

S = unit stress in the steel added
L = length in inches of steel added
D = degrees Fahrenheit
C = linear coefficient of expansion per deg. F.
E = Young's modulus of elasticity.

(2). *How may the change in temperature with corresponding unit stress be most simply determined and secured?*

By welding one end of the new steel to the old steel and heating the new steel until its length increases an amount equal to *DCL;* then while the new steel is hot, weld the other end, and complete the intermediate welding.

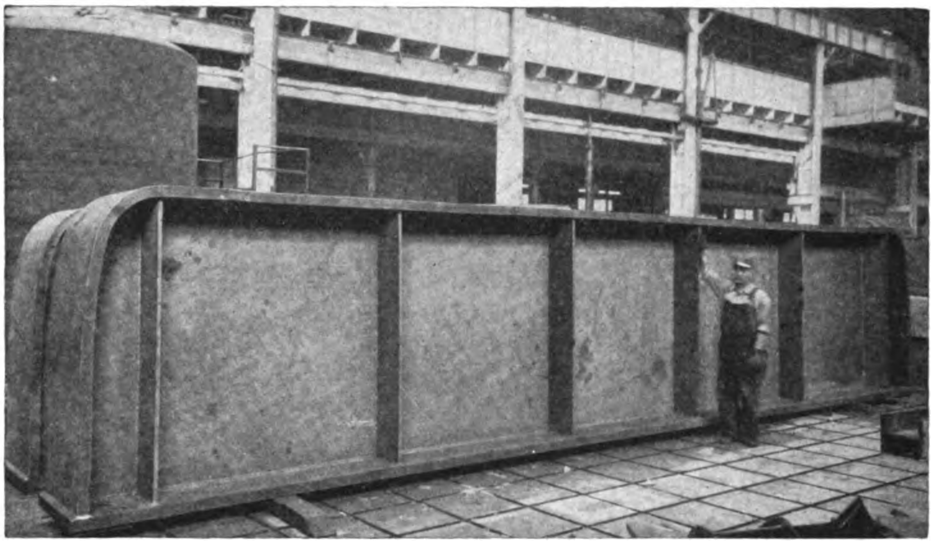


Fig. 1. Fabricated Welded Girders for Upper Bearing Bracket of 19,000-kv-a. Waterwheel Generator

For example: Suppose it is desired to cause a stress of 10,000 lb. per sq. in. in an added plate having a length of 300 in., how many degrees Fahrenheit must the plate be heated and what will be the corresponding increase in length?

$$D=\frac{S}{EC}=\frac{10{,}000}{30{,}000{,}000\ (0.000{,}007)}$$

$$=50 \text{ deg. F. (approx.)}$$

Increase in length

$$=DCL=50\ (0.000{,}007)\ 300=1/10 \text{ in.}$$

or more directly, increase

$$=\frac{SL}{E}=\frac{10{,}000\ (300)}{30{,}000{,}000}=1/10 \text{ in.}$$

The present tendency in electric arc welding is toward the use of higher currents and automatic welding machines. This is particularly true of the manufacture of steel pipes wherein machine welding is widely used. And, although for ordinary shop buildings the steel is welded by hand with currents from about 175 to 200 amp. for 3/8-in. fillets, there is a distinct trend to use machine welding in fabricating plate girders and other similar parts where long lines of welds are required. For hand arc welding in buildings, uncoated medium-steel electrodes with carbon content of 0.0013 to 0.0018 are used extensively, in fact, almost universally; but in steel-pipe manufacture coated or sheathed electrodes are employed quite commonly. Steel to be welded should not be painted before welding. The best practice is to give the steel one coat of linseed oil after the shop welding is performed; ship, erect, and weld the steel in the field and finally paint it.

Practically all welding on buildings and bridges has been done with the arc, although a large steel building has just been completed with all shop and field welding accomplished by oxy-acetylene.

In the General Electric Company's welded building at West Philadelphia, the use of welding resulted in a very considerable saving of weight as compared with riveted construction for carrying the same load. For example: For roof trusses of 58 ft. 6 in. span designed for welding, the actual weight per truss was 5000 lb. as compared with 6800 lb. for a riveted truss performing the same function, a saving of 1800 lb. per truss; for trusses of 78 ft. span, the weights were 9200 lb. for welded and 13,200 lb. for riveted trusses carrying identical loads, a saving of 4000 lb. per truss.

In multi-story buildings the saving of steel is not so apparent; in fact, unless the beams are made continuous, welding results in very little if any saving. And this continuity frequently costs more than it is worth, because the extra welding at the ends of beams to secure continuity costs more than the saving in steel effected in the main body of the beams.

In plate-girder construction the use of welding results in a considerable saving in weight of steel. For example: A series of two riveted and four welded designs for girders of 40-ft. spans, each carrying 160,000 lb. uniformly distributed over its entire length, indicates that a saving of weight of steel of 27.1 per cent can be secured by welding. In this series, the riveted girder weighs 7498 lb.; the welded girder 5467 lb., a saving of 2031 lb. (27.1 per cent).

Fig. 1 represents two welded plate girders built in the General Electric Company's shops for a power plant to serve as the upper bearing bracket of a 19,000-kv-a. waterwheel generator. No rivets were used in its construction.

In the principal cities and towns, building codes are in force designed to secure safer building construction; and where municipalities have recently adopted revised codes, a provision for welding has in general been incorporated. To date, 63 cities and towns have adopted welding and many of the larger cities, including New York, have the subject under consideration. The latter city has drafted a new code which includes welding, but final action has not yet been taken on it.

The American Welding Society's Code for Fusion Welding and Gas Cutting in Building Construction gives the following permissible unit stresses for use in designing structural details under static loads and these units are recommended for use where applicable:

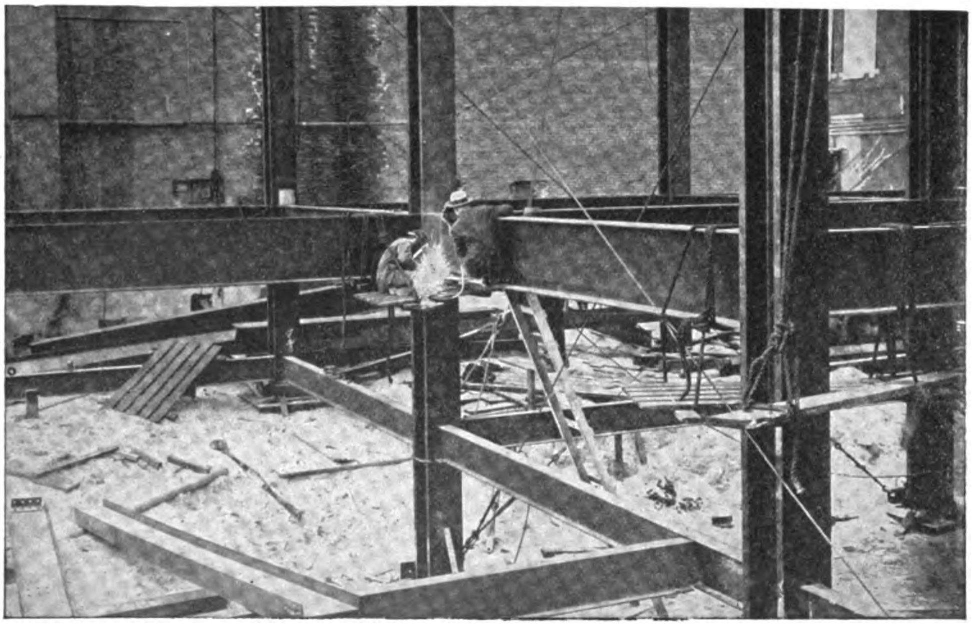
> "Welded joints shall be proportioned so that the loads specified in the Building Code shall not cause stresses therein to exceed the following amounts in pounds per square inch:
>
> | | |
> |---|---|
> | Shear on section through throat of weld..... | 11,300 |
> | Tension on section through throat of weld... | 13,000 |
> | Compression on section through throat of weld | 15,000 |
>
> Maximum fiber stresses due to bending shall not exceed the values prescribed above for tension and compression respectively.
>
> In designing welded joints adequate provision shall be made for bending stresses due to eccentricity, if any, in the disposition of section of base metal parts."

Much attention is being given to the testing of welders to ascertain whether they are qualified to perform welding on important structures; and to the inspection of the welding as it progresses. In the opinion of the writer, both of these are necessary but the qualification of welders is more important. This is ascertained by testing welds made by the workmen. Both lap and butt joints are made, cut into standard test specimens and tested to determine the tensile strength of butt welds or the shearing strength of lap welds. For arc-welded buildings the greater number of joints are so designed as to throw fillet welds into longitudinal shear, *i.e.*, the shearing force is parallel with the length of the fillet.

The value of 11,300 lb. per sq. in. given in the American Welding Society's Code has come to be generally used for joints bearing quiescent loads. For a fillet with triangular cross section and with base and altitude of the triangle each $\frac{3}{8}$ in., this corresponds to a permissible safe strength in longitudinal shear of 3000 lb. per linear inch of fillet; for $\frac{5}{16}$-in. fillets, 2500 lb. per linear inch.

By placing two tungsten wire electrodes at an angle to each other with a short space between their converging ends, and passing alternating current through the circuit to form an arc in the air space between them, then forcing hydrogen gas into this arc, an intense heat is produced; exceeding that of the arc itself. This results from the dissociation of the hydrogen molecule, *i.e.*, the breaking it up into its two atoms, which upon reuniting, create an intense heat. This heat is utilized to melt two pieces of steel together, thus welding them. If additional metal is required in the production of fillets, a wire or rod must be melted in the heated zone to give the excess material necessary to form the fillet.

To date this atomic-hydrogen welding has met with great success in uniting various non-ferrous metals, or very thin ferrous parts, but it has not been tried to any extent in welding the thicker steels in structures like bridges and buildings. But it has possibilities. The principle underlying it is sound.



Economies of Electric Traction for Trunk Line Railroads

Comparative Costs of Steam and Electric Operation—Savings Resulting from Electrification—Installation Costs—Gas-electric Cars—Oil-electric Locomotives

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(A paper presented at the World Power Conference, Berlin, Germany, June 16-25, 1930)

THE electrification of steam railroads in the United States began about 1894; since that time electricity has been applied to the operation of various types of equipment, including the following:

(1). Main line electric locomotives.
(2). Multiple-unit motor car trains.
(3). Gas-electric motor cars.
(4). Oil-electric locomotives.

There are today in the United States approximately 600 locomotives handling freight, passenger, and switching service on trunk line railroads. Multiple-unit trains in terminal service on steam railroads, and similar equipment used by rapid transit lines in large cities, include approximately 2700 motor cars. Self-propelled locomotives, principally of the so-called oil-electric type, number nearly 100 units. A larger number of these locomotives are in service in small switching yards where the volume of traffic is not heavy enough to justify the installation of overhead distribution and substation power. An outstanding example of this application, using 36 locomotives, is the New York City District of the New York Central Railroad. Electrification of the "West Side" tracks is being completed southward to include the Sixtieth Street Yards. Below these yards all freight movement will be handled by oil-electric battery locomotives, which are a modification of the straight oil-electric unit, carrying a large storage battery to furnish a high emergency tractive effort.

The oil-electric locomotive has not, so far, been adapted to any great extent to the handling of main line freight and passenger trains. One unit equipped with an 825-hp. engine and generator is in operation on the Putnam Division of the New York Central Railroad, handling branch line freight trains. Another similar unit of 880-hp. is handling passenger trains on the same division. Some experiments have also been made by the Canadian National Railways using a two-unit locomotive having a total rating of 2660 hp.

Another application of electricity which has assumed a good deal of importance in the United States in the past few years, for handling passenger service, is the gas-electric motor car. This type of motive power is particularly suited to the many light traffic, branch, and feeder lines, which form a part of large railroad systems. On account of the diversion of an extensive passenger business, which was formerly handled by these lines, to private automobiles and buses, it has been difficult to justify the cost of operating full crew steam trains. The gas-electric motor car has shown unusual savings, due in part to the smaller train crew required and to the lighter weight, which has naturally resulted in a lower fuel cost. As with the electric locomotive there has also been a saving due to the reduction in repair costs.

Electrification Economies

For many years after the introduction of electric traction no electrifications were undertaken solely for reasons of economy. A number of the earlier projects were carried out principally to eliminate the smoke and soot nuisance, and for the more expeditious handling of terminal passenger traffic. For these reasons there was little opportunity for setting up a convincing direct comparison between the cost of steam and electric operation. More recently, with the adaptation of electric haulage to some of our main line roads, accurate and reliable figures have been compiled, detailing item by item the relative costs of steam and electric operation.

Accounting methods, prescribed by the Interstate Commerce Commission for American railroads, provide for a distinct segregation of the operating costs as distinguished from overhead charges such as interest and depreciation. In analyzing the figures given herewith, therefore, it is sometimes desirable to take into account the investment involved in electrification in order to determine the net benefits resulting from the conversion. Such figures, where available, are included in this article.

Butte, Anaconda & Pacific Railway

One of the first electrifications of which it was possible to make a direct comparison between the cost of steam and electric operation was the Butte, Anaconda and Pacific Railway, operating a heavy freight line between the mines at Butte and the smelters at Anaconda, (Mont.). The initial operation of the electrical equipment on this road was in May, 1913. The figures used in Table I are for steam operating for the six months prior to electrification, and for electrical operation for the six months following electrification. The tonnage handled was somewhat heavier under electric operation and adjustment has been made for this difference.

It will be noted that the largest saving shown in this comparison is in fuel as contrasted with power. In general the cost of coal in the United States will not very far exceed the cost of electric power, at present rates, for handling the same service; however, the Butte, Anaconda and Pacific Railway was able to secure a very attractive electric power rate and as a result shows the indicated economies. The savings secured in the item of crew wages are a result of operating heavier trains at higher speeds with a single engine crew. The third important item of saving is in locomotive repairs. It will be noted that this item is consistently higher on most other railroads.

Chicago, Milwaukee, St. Paul & Pacific Railroad

The next important comparison of steam and electric operation was made by the Chicago, Milwaukee and St. Paul Railway after several years of electric operation on two divisions, one 440 miles in length (formerly four steam divisions), and the other 220 miles in length (formerly two steam divisions). This comparison is the result of an exhaustive study made by the engineers of the railroad company at the request of the president of the railroad. Tables II and III show the comparison of operating costs on the Harlowton-Avery Division and the Othello-Tacoma Division of this road. In both cases the highest percentage of saving is shown in locomotive repairs.

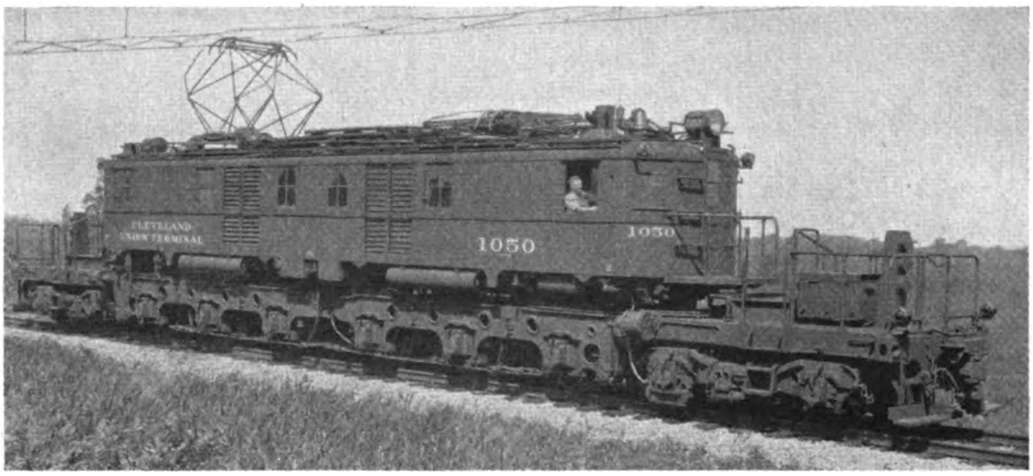

Fig. 1. 204-ton High-speed Passenger Locomotive, Cleveland Union Terminals, Cleveland (O.)

TABLE I

BUTTE, ANACONDA & PACIFIC RAILWAY

Comparison of Ton-mile Operating Costs and Savings (1913 Basis)

	COST PER 1000 TON-MILES		SAVING	
	Steam	Electric	Amount	Per Cent of Steam
Enginemen	$0.71	$0.41	$0.30	42
Trainmen	1.00	0.67	0.33	33
Fuel or power	2.14	0.954	1.186	55
Repairs	0.85	0.535	0.315	37
Enginehouse	0.20	0.107	0.093	46
Lubricants	0.066	0.029	0.037	56
Other supplies	0.04	0.027	0.013	36
Water	0.034	0.007	0.027	80
Substations	....	0.097	....	..
Trolley and trans.	....	0.104	....	..
TOTAL	$5.05	$2.94	$2.11	42

Paulista & Mexican Railways

Outside of the United States the cost of fuel is usually an important item. Tables IV and V, giving respectively the operating costs of the Paulista Railway in Brazil and the Mexican Railway in Mexico, illustrate this condition. It will be noted, however, that the savings in repairs to equipment are still of major importance on these roads. In studying these figures it will be seen that the expenditures for the maintenance of substations and distribution systems are relatively small when compared to the total

TABLE II

CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC RAILROAD

HARLOWTON-AVERY DIVISION

Comparison of Ton-mile Operating Costs and Savings (1923 Basis)

	COST PER 1000 TON-MILES		SAVING	
	Steam	Electric	Amount	Per Cent of Steam
Enginemen	$0.258	$0.145	$0.113	43.5
Trainmen	0.217	0.142	0.075	34.5
Fuel or power	0.551	0.34	0.211	38
Repairs	0.433	0.15	0.283	65
Enginehouse	0.103	0.0386	0.064	62
Lubricants	0.008	0.0067	0.0013	20
Other supplies	0.011	0.003	0.008	72
Water	0.012	....	0.012	..
Substations	....	0.0484	....	..
Trolley and trans.	....	0.029	....	..
TOTAL	$1.59	$0.903	$0.687	43

TABLE III
CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC RAILROAD
OTHELLO-TACOMA DIVISION
Comparison of Ton-mile Operating Costs and Savings (1923 Basis)

	COST PER 1000 TON-MILES		SAVING	
	Steam	Electric	Amount	Per Cent of Steam
Enginemen	$0.324	$0.183	$0.141	44
Trainmen	0.36	0.22	0.14	39
Fuel or power	0.69	0.43	0.26	38
Repairs	0.47	0.19	0.28	55
Enginehouse	0.081	0.043	0.038	47
Lubricants	0.008	0.007	.....	..
Other supplies	0.010	0.007	0.003	30
Water	0.017	....	0.017	..
Substations	....	0.085	....	..
Trolley and trans.	....	0.05	....	..
TOTAL	$1.96	$1.22	$0.74	38

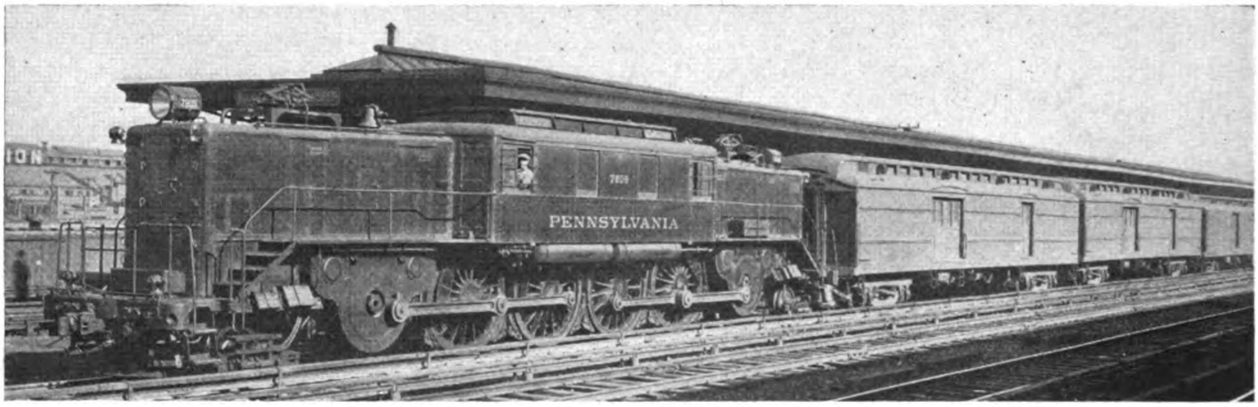

Fig. 2. 200-ton Passenger Locomotive in Service on the Pennsylvania Railroad, New York Terminal

operating cost. In all of the items listed, constituting the principal costs of operation affected by electrification, there is a substantial saving in each installation.

With the single exception of the Paulista Railway the figures given are based on a comparison of steam operating costs prior to electrification with electric operating costs after the change-over. The figures, therefore, cover identical conditions of profile and approximate train service. A somewhat different method is employed in comparing the operations on the Paulista Railway. It was found in studying the available figures that data could be compiled covering the electric operations in the initial electric zone, and at the same time figures covering steam operation on an adjacent steam operated section handling practically the same class of service. A comparison is thus made between two similar services, one electric and the other steam operated, at the same period of time.

Although these comparisons were made at different times covering various traffic conditions and profiles, with different labor and supply prices, it is nevertheless well worthy of note that a uniform saving is shown over steam operation. For this reason the consolidation of the fundamental data given in Table VI is of interest; not so much from the standpoint of the amounts involved, but rather on account of the percentages of saving shown by the entire group.

The costs for handling 1000 ton-miles of traffic by steam are shown in the foregoing tables to range between $1.43 and $5.05. The range of costs after electrification varies from $0.53 to $2.94. Conditions of profile, speeds, density of traffic, and other physical

TABLE IV
PAULISTA RAILWAY
Comparison of Ton-mile Operating Costs and Savings (1927 Basis)

	COST PER 1000 TON-MILES		SAVING	
	Steam	Electric	Amount	Per Cent of Steam
Enginemen	$0.425	$0.12	$0.305	72
Trainmen	....	....	....	..
Fuel or power	1.73	0.25	1.48	85
Repairs	0.267	0.045	0.222	83
Enginehouse	0.328	0.0655	0.263	80
Lubricants	0.05	0.01	0.04	79
Other supplies	0.14	0.050	0.09	65
Water	....	....	....	..
Substations	....	0.056	....	..
Trolley and trans.	....	0.055	....	..
TOTAL	$2.94	$0.652	$2.288	78

TABLE V
MEXICAN RAILWAY
Comparison of Ton-mile Operating Costs and Savings (1928 Basis)

	COST PER 1000 TON-MILES		SAVING	
	Steam	Electric	Amount	Per Cent of Steam
Enginemen	$0.248	$0.117	$0.131	53
Trainmen	0.174	0.086	0.088	50
Fuel or power	0.401	0.249	0.152	38
Repairs	0.545	0.048	0.497	91
Enginehouse	0.031	0.015	0.016	50
Lubricants	0.026	0.0007	0.025	97
Other supplies	....	....	....	..
Water	....	....	....	..
Substations	....	0.017	....	..
Trolley and trans.	....	0.007	....	..
TOTAL	$1.43	$0.534	$0.90	62

factors influence these costs, but on similar roads the comparisons should be assumed most accurate.

To supplement the operating costs given in Table VI, the costs of installing electrical equipment, together with other statistics, are shown in Tables VII to X inclusive.

TABLE VI

COMBINED RESULT

Comparison of Operating Costs and Savings (Composite Average)

	OPERATING COSTS		SAVING	
	Steam	Electric	Amount	Per Cent of Steam
Enginemen	$1,415,283	$685,792	$729,491	51.5
Trainmen	1,128,539	664,787	463,752	41
Fuel or power	3,466,385	1,570,367	1,896,018	55
Repairs	2,108,437	632,360	1,476,077	70
Enginehouse	533,307	184,071	349,236	65.5
Lubricants	82,932	33,184	49,748	60
Other supplies	117,199	44,353	72,846	62
Water	48,406	1,194	47,212	97.5
Substations	......	231,884	......	....
Trolley and trans.	......	154,072	......	....
TOTAL	$8,900,488	$4,202,064	$4,698,424	52.7

Motor Car Operation

From the operating viewpoint, the motor-car train in comparison with steam operation possesses many advantages. Its freedom from objectionable smoke and steam permits operation underground and in terminals without restriction. The reversible feature permits faster handling and a reduction of the number of train movements in terminals. The high emergency capacity of its motors permits an acceleration far in excess of a train handled by a steam locomotive. Inherently, the electrically propelled unit costs less to maintain and has a higher availability with a resulting advantage of a greater number of hours of service per year.

The cost of maintaining electric motor cars varies quite widely with the service, usually being the lowest in such heavy traffic duty as is required of subway and elevated rapid transit lines.

In practically every installation the substitution of motor cars for steam-handled trains has resulted in an improvement in the balance sheet due to increased riding. In the case of the Illinois Central Railroad, according to Mr. L. A. Downs, President, the suburban traffic for the year 1927 was one-third greater than in June, 1926, immediately prior to the change-over. There was an increase of 4,500,000 rides in 1927 over the previous year. There were, in 1928, 535 electric trains operating daily as compared to a peak service of 398 trains under steam operation. Advantage has been taken of the greater speed possibilities with motor car trains and the running time has been reduced between 11 and 28 per cent. As a result, the suburban passenger service of the Illinois Central Railroad, which for many years had been a financial burden, has been made to pay its own way. In addition, a substantial improvement in property values has been obtained as a by-product of electrification in the air rights made available by the use of electric power.

TABLE VII

BUTTE, ANACONDA & PACIFIC RAILWAY INSTALLATION COSTS

Initial Electrification, 1913; Route Miles, 30; Miles Single Track, 91

Power substation apparatus	$118,950
Power substation building	191
Power distribution system	357,009
Power line poles and fixtures	135,264
Other expenses	47,176
Electric locomotives	553,000
TOTAL	$1,211,590
Cost per route mile	40,000
Cost per mile single track	13,400

TABLE VIII

CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC RAILROAD

ROCKY MOUNTAIN & MISSOULA DIVISIONS (1915)

INSTALLATION COSTS

Route Miles, 438; Single Track Miles, 566

Power substation buildings	$535,157
Power substation apparatus	1,859,353
Power transmission system	715,181
Power distribution system	2,890,615
Power line poles and fixtures	1,091,721
Signal system	197,446
Other expenses	452,216
Locomotives, freight	2,881,112
Locomotives, passenger	927,408
Locomotives, switchers	111,564
TOTAL	$11,661,773
Cost per route mile	26,650
Cost per mile single track	20,600

TABLE IX

CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC RAILROAD

COAST DIVISIONS (1919)

INSTALLATION COSTS

Route Miles, 210; Single Track Miles, 282

Power substation buildings	$452,808
Power substation apparatus	1,476,964
Power transmission system	549,521
Power distribution system	2,190,401
Power line poles and fixtures	966,563
Signals	780,000
Other expenses	762,734
Locomotives, freight	3,065,280
Locomotives, passengers	1,035,690
Locomotives, switchers	48,520
TOTAL	$11,328,481
Cost per route mile	50,400
Cost per mile single track	40,000

TABLE X

MEXICAN RAILWAY CO., LTD.

ESPERANZA-PASO DEL MACHO

INSTALLATION COSTS

Route Miles, 64; Single Track Miles, 80

Power substation buildings	$686,919
Power transmission system	263,130
Power distribution system	633,327
Power line poles and fixtures	286,134
Other expenses	157,427
Locomotives	1,580,000
TOTAL	$3,606,937
Cost per route mile	56,358
Cost per mile single track	45,000

Another rapid transit line which has recently been converted to electric operation is that of the Boston, Revere Beach and Lynn Railroad handling a heavy suburban traffic between Boston, Lynn, and intermediate suburban residential sections. According to the officers of this road, which began operation in November, 1928, the passenger revenue for May, June and July of 1929 showed an increase of 10.2 per cent over the same period for the previous year. The actual number of passengers carried increased 10.3 per cent. There was an increase of 1.58 per cent in the number of car miles operated so that the increased riding must be, for the most part, attributed to faster, more regular and cleaner service provided by electric trains.

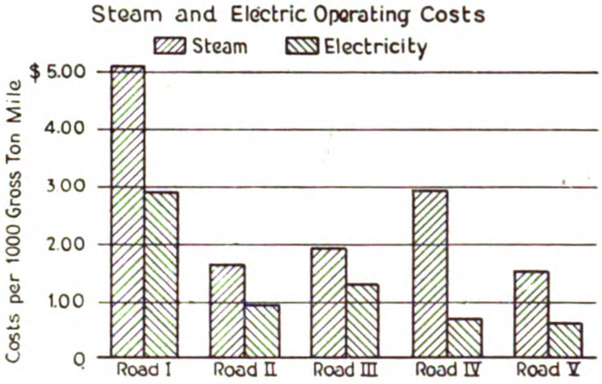

Fig. 3. Comparison of Steam and Electric Operating Costs Per 1000 Gross Ton-miles on Five Roads

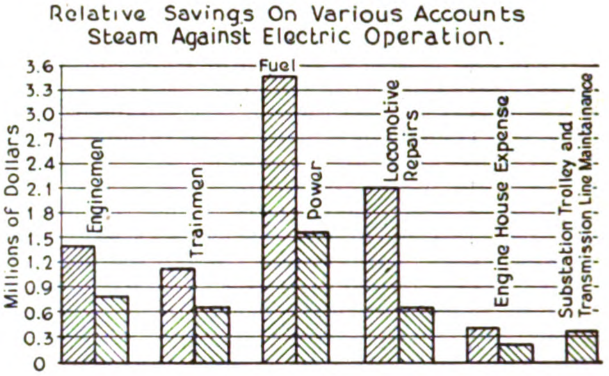

Fig. 4. Relative Savings on Various Operating Accounts of a Group of Five Electrified Roads

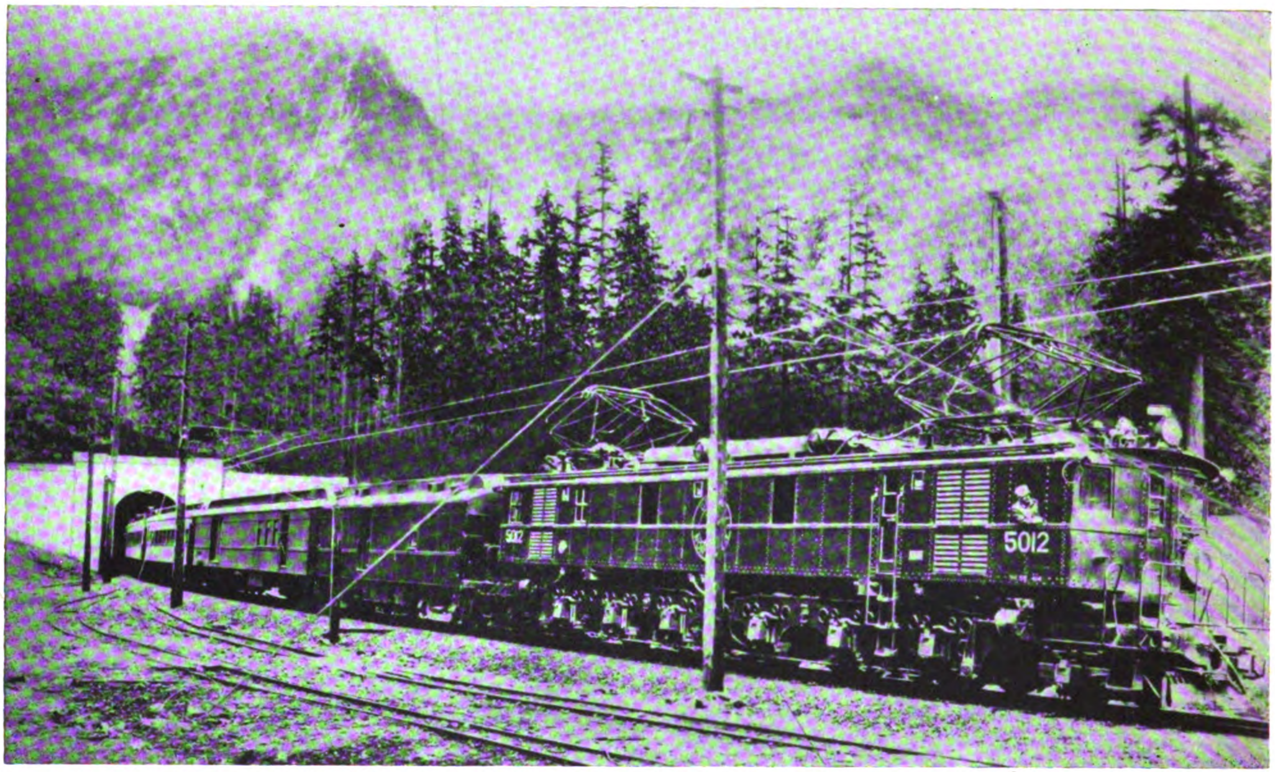

Fig. 5. Great Northern 260-ton Motor-generator Type Locomotive and Passenger Train at New Cascade Tunnel, West Portal

The railway operating expenses, in spite of the increase in the number of miles operated, show an actual decrease of 18.8 per cent for the first six months of 1929. As a result of the reduced cost of operation there has been a decided improvement in net income.

In reaching a decision to electrify its suburban service out of Hoboken, the Delaware, Lackawanna and Western Railroad has indicated a full appreciation of the possibilities of electric operation as outlined here. Another recent installation of a similar character is that of the Staten Island Rapid Transit Company, which is operating trains electrically between the ferries and residential points on Staten Island. A number of other steam railroads have been taking advantage in recent years of motor car operation for suburban passenger traffic. The Pennsylvania Railroad, New York Central Railroad, Long Island Railroad, the Southern Pacific Company, and a number of others have demonstrated to their own satisfaction the desirability of eliminating, where possible, the use of the steam locomotive in handling suburban passenger service.

Gas-electric Motor Cars

Although the application of electric drive to self-propelled motor cars was first tried out more than 25 years ago, it is only in the last few years that there has been a general acceptance of this substitute for steam power by the railroads of the United States. At the close of the World War the rapid increase in the cost of railroad operation and the competition of privately owned automobiles and buses gave emphasis to the necessity for a reduction in the cost of handling passenger traffic on branch lines and at the same time provision for an improvement to the service to attract riders. Recently operating costs have become available on a number of roads demonstrating the effectiveness of this type of motive power. Table XI, based on a typical installation, indicates the advantage of the self-propelled motor car over steam operation.

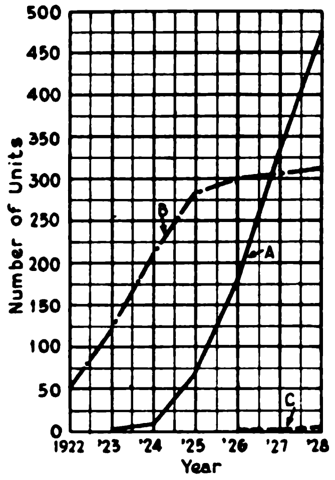

Fig. 6. Curves Showing Total Rail Motor Cars of Various Types in Operation, 1922 to 1928

Curve *A*: Gas-electric
Curve *B*: Gas-mechanical
Curve *C*: Oil-electric

TABLE XI

STEAM AND GAS-ELECTRIC TRAINS

	COSTS PER TRAIN-MILE (CENTS)	
	Steam Train	Gas-electric
Wages: engine and train crews	28.5	17.9
Fuel: coal or gasoline	28.0	8.01
Lubricant	1.01	1.01
Terminal inspection and engine-house expense	2.0	1.25
Labor: cleaning, icing, and watering	1.18	0.92
Miscellaneous supplies	0.75	0.52
Repairs: labor and material, total train	21.0	5.0
Sub-total	82.5	34.61
Depreciation at 10 per cent	...	7.15
Interest at 6 per cent	...	4.3
GRAND TOTAL	82.5	46.06

A still more detailed statement in Table XII shows the cost of operating two gas-electric motor cars, each handling a 35-ton trailer, and operating an average of 251 miles a day. The figures given in this table show the result of ten months' operation.

TABLE XII

COST OF TEN MONTHS' OPERATION OF TWO GAS-ELECTRIC MOTOR CARS

(Average Trip 251 Miles Daily with 35-ton Trailer—Train Weight 83 Tons—Power Plant 225-hp. Engine)

Total motor car-miles	141,062
Total steam train-miles	8,132
Total train-miles	149,094
Gasoline: gallons	73,461
Cost: gasoline per gallon (cents)	13.18
Train-miles per gallon	1.92
Car-miles per gallon	3.76
Lubricating oil: gallons	2,017
Cost of oil per gallon (cents)	50.28
Train-miles per gallon	71.16
All expense per train-mile, including interest, depreciation and steam service (cents)	35.23

Cost Per Train-mile (Cents)

Repairs: labor	1.30
Repairs: material	0.83
Fuel: gasoline	6.84
Lubricants	0.74
Enginehouse expense, inspection	1.26
Other supplies and expense	1.28
Wages: train and engine crew	15.15
Sub-total	27.41
Substitute steam service	2.43
Interest on investment	2.90
Depreciation	2.49
GRAND TOTAL (cents per train-mile)	35.23

Summary

Total scheduled mileage, 10 months' operation	149,094 miles
Total motor car mileage	141,062 miles
Total steam-train mileage	8,032 miles
Total steam-train mileage due to heavy traffic	6,024 miles
Total steam-train mileage due to motor cars out for repairs (equivalent to four round trips)	2,008 miles
Percentage of scheduled mileage covered by motor cars	98.7 per cent

Records are also available showing the cost of operating seventeen of these motor cars over a period of twelve months (Table XIII). These operating costs are typical of many large installations and the total figure (31.9 cents per train-mile) cannot be approached by steam-handled trains.

TABLE XIII

TYPICAL OPERATING COSTS OF 17 CARS OVER A PERIOD OF 12 MONTHS

Availability	91.7 per cent
Total miles	986,753
Average cost (less fixed charges)	31.9 cents per train-mile
Repairs and material	3.3 cents per train-mile
Operation (including wages, fuel and roundhouse expense)	28.6 cents per train-mile

Oil-electric Locomotives

The oil-electric locomotive is an adaptation of the Diesel engine, which takes advantage of the fuel efficiency possible with this type of power unit, and at the same time the flexibility of transmission secured with electric drive. Careful studies of installations, in service a sufficient length of time to give accurate operating results, have borne out the predictions of the sponsors of this type of motive power as regards operating costs. The figures given in Table XIV show a comparison of the cost of operating a 300-hp. oil-electric locomotive and a 72-ton steam locomotive which it replaced. These figures cover the complete year of 1928 and are reduced to cost per locomotive hour.

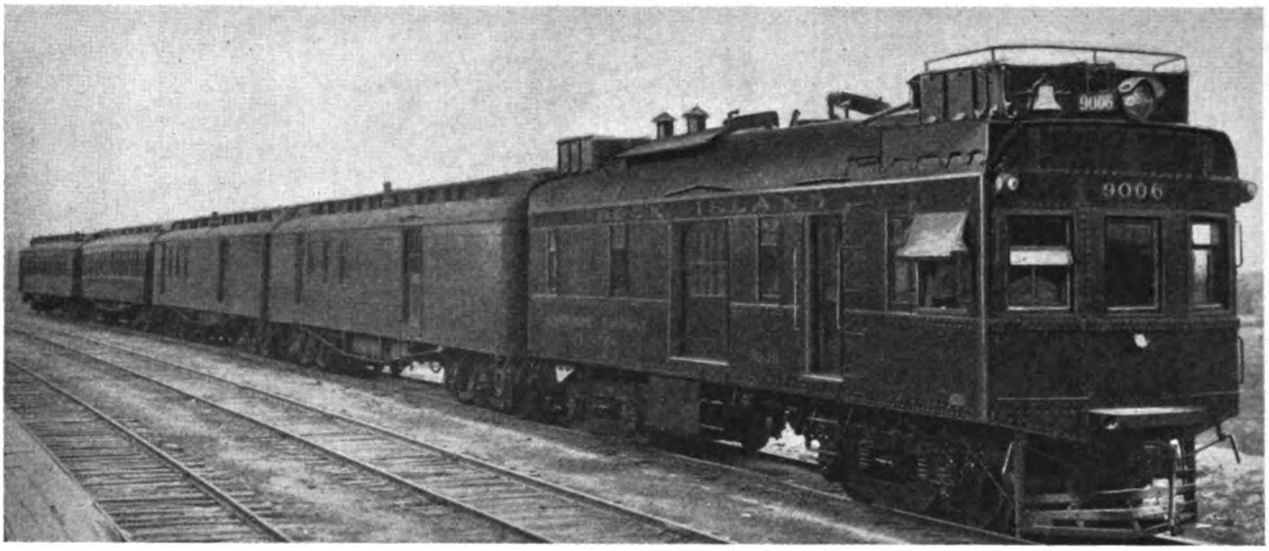

Fig. 7. 800-hp. Rail Motor Car Hauling Four Passenger Trailers, Chicago, Rock Island and Pacific Railroad. Equipment includes two 400-hp. distillate-burning engines

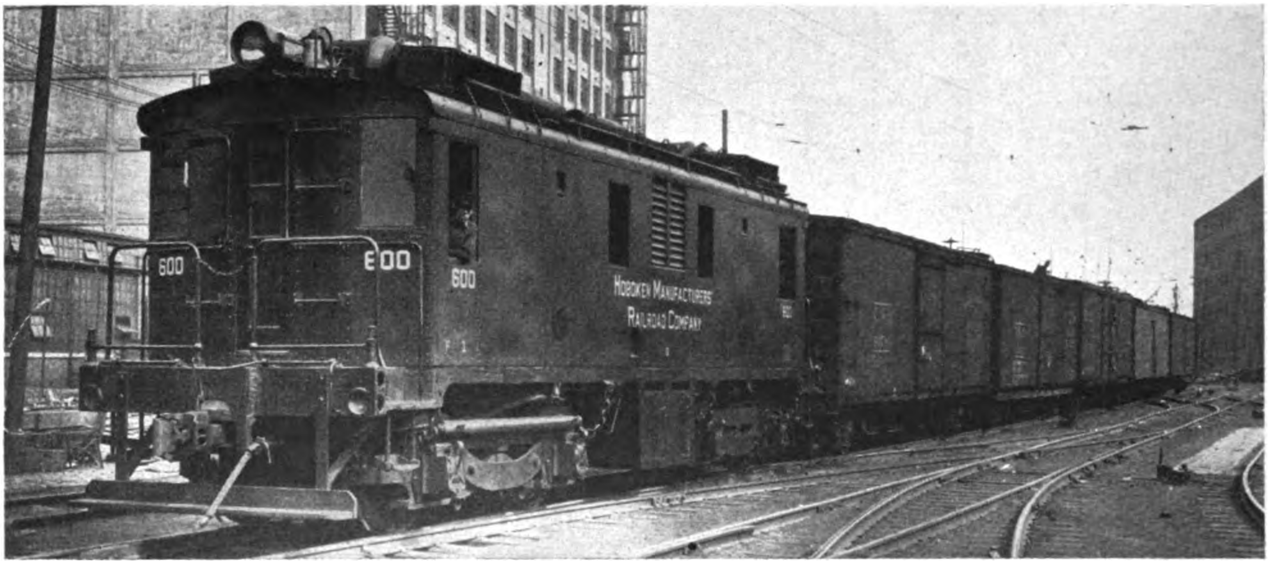

Fig. 8. Hoboken Manufacturer's Railroad; 110-ton Oil-electric Switching Locomotive and Train

TABLE XIV

COST OF OPERATION PER LOCOMOTIVE HOUR

Twelve Months of 1928

	Oil-electric	Steam
Labor	$1.660	$3.310
Fuel	0.365	1.210
Supplies	0.080	0.020
Repairs: Material and Labor	0.560	1.070
Enginehouse	0.205	0.795
Depreciation	0.815	0.115
Superintendence	0.895	1.065
Interest	0.505	0.115
TOTAL	$5.085	$7.700

Average saving per hour by the oil-electric locomotive. $2.615

Conclusion

Electricity is invading the steam locomotive field at almost every point. Beginning many years ago with the replacement of steam power in tunnels and terminals, it has gradually taken over heavy traction suburban passenger service, steep grade mountain sections, usually the most difficult to operate of any portion of the railroad, and recently the lighter traffic branch lines where a gas-electric motor car has demonstrated its superiority. Still more recently the light traffic switching yard is employing the oil-electric locomotive as a most satisfactory substitute for steam power.

In connection with many existing electrifications, the electric locomotive has demonstrated its superiority both in main line passenger and freight service. In connection with other electrification work, congested switching yards are being electrically operated with appreciable economy. It is probable, however, that for many classes of service the steam locomotive will give satisfaction for many years. In most operating studies made after electrification, advantages have been found which have exceeded the expectations of the advocates of electric operation. In other words, the claims of the proponents of electrification have been uniformly conservative. Although the figures used in this paper have been limited to American practice, it is well known that comparable results have been secured in other parts of the world. It is a fact, moreover, that the United States, due to a large extent to the low price of coal and fuel oil, has probably progressed less rapidly in the adoption of electrical equipment on steam railroads than most other countries. Improvements now in progress and plans being seriously studied in this country, however, indicate a more rapid acceptance of electricity by the railroads within the next few years.

General Panoramic View of an Electrified Section of the Mexican Railway

Inductance—and a Simple Laboratory Means For Its Determination

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ONE of the most important characteristics of a circuit is its inductance, and in order to know and understand the complete behavior of the circuit when under both steady-state and transient conditions this property must be known. In many cases the inductance can be calculated, even though considerable mathematics is required in the process; but often the circuit under study does not lend itself to such methods, and means of obtaining this quantity by test must be employed. It is the purpose of the writers to briefly consider inductance itself and to present a method which has been used to determine the self-inductance of a coil—a simple and practical laboratory method which makes use of a ballistic galvanometer and direct current.

Definition of Self-inductance

It is a physical fact that a magnetic field is associated with every current, the strength of the field increasing and decreasing as the current increases and decreases. If saturation does not exist the relation between current and flux is linear. As the current in a coil varies, the flux produced by the current, in building up about the circuit and in collapsing upon it, induces a voltage in the conductors, the magnitude of this voltage depending upon the number of turns of the circuit and the rate at which the flux changes through those turns.

Expressed symbolically, the voltage of self-induction is often given as

$$e = -n\frac{d\phi}{dt} \times 10^{-8} \text{ volts} \tag{1}$$

the negative sign denoting opposition of the voltage to the change of flux. This expression assumes that all of the turns link all of the flux, which in general is not true, and in many cases would give calculated results far from the correct values. Some of the flux does link all of the turns, but some flux links fewer turns, and still fewer turns are linked by less flux, as shown in Fig. 1. These partial linkages, if we may give them that name, contribute their share towards the total e.m.f. induced in the circuit just as do the total linkages, and to thus form a general mathematical relation for the voltage of self-induction it is convenient to write

$$e = -\frac{d\Omega}{dt} \times 10^{-8} \text{ volts} \tag{2}$$

in which Ω represents the summation of the circuit linkages, both total and partial.

$$\Omega = \sum n\phi \tag{3}$$

Since the induced voltage depends upon the rate of variation of flux, and the flux in turn depends upon the current, the self-induced voltage will therefore vary in some manner with the current. Hence, mathematically, it is usual to say also that

$$e = -L\frac{di}{dt} \text{ volts} \tag{4}$$

The factor L is not necessarily a constant, but is simply the measure of proportionality between voltage and time rate of variation of current. From the preceding voltage equations it is thus readily observed that, in general

$$L = \frac{d\Omega}{di} \times 10^{-8} \tag{5}$$

The quantity L is called the coefficient of self-inductance of the circuit and is expressed in henries. Physically, the inductance of a circuit is a geometric property of that circuit and depends upon the reluctance of the magnetic path, which in general is not a constant because of the variable permeability of the medium when iron is present. As viewed from Equation (5), the inductance is directly proportional to the slope of the saturation curve for the circuit, as shown in Fig. 2. Below the point of saturation the inductance is constant and is spoken of as the flux linkages of the circuit per ampere of current producing that flux. That is, without saturation

$$L = \frac{\Omega}{i} \text{ henries.} \tag{6}$$

For convenience, the self-inductance of a circuit is defined from Equation (4) as numerically equal to the voltage produced in that circuit by the rate of change of one ampere per second through it. For purposes of general calculation this definition may perhaps be the most useful, but it must be remembered that the self-induced voltage depends upon the magnitude of the current as well as upon its rate of variation. If saturation exists beyond an exciting current of say 10 amp., the induced voltage will be greater when the current is changing from 3 to 4 amp. than when it is changing from 13 to 14 amp., assuming that these current variations occupy equal periods of time.

Definition of Mutual Inductance

Two or more electrical circuits are said to be coupled when some of the magnetic flux produced by current in one of the circuits links with all or some of the turns of the other circuits, as in Fig. 3. Under such a condition, current varying in the first circuit can produce a voltage in the other circuits by virtue of these changes in mutual linkages, and hence these other circuits are said to possess the property of mutual inductance.

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In general, mutual inductance, M, is thus defined mathematically as

$$M_{mn} = \frac{d\Omega_{mn}}{di_m} \quad (7)$$

which states that the mutual effect produced by circuit m upon circuit n is equal to the rate of change of the mutual linkages of these circuits with respect to the current in circuit m. Similar to the definition for self-inductance, mutual inductance is defined as being numerically equal to the voltage produced in circuit n by the rate of change of one ampere per second in circuit m.

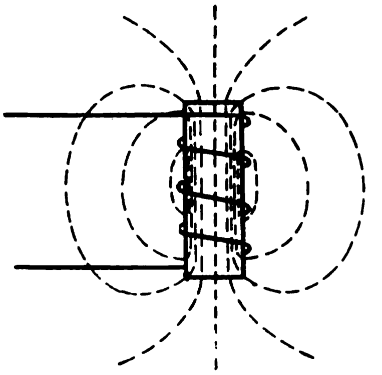

Fig. 1. Magnetic Field About an Iron-core Solenoid, Showing Total and Partial Flux Linkages of the Self-induced Field

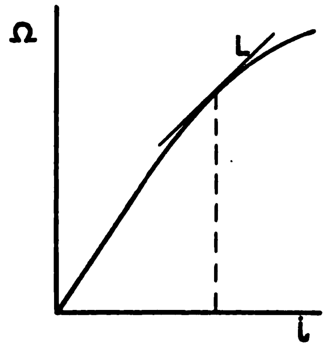

Fig. 2. The General Saturation Curve, Showing How the Inductance at Any Point May be Determined as the Slope of the Curve at That Point

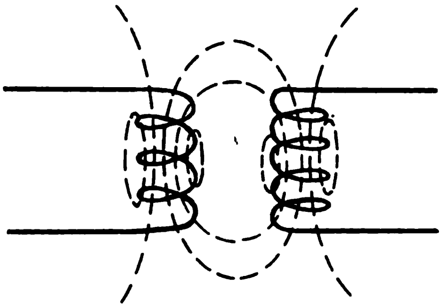

Fig. 3. Two Coupled Circuits, Showing Mutual Flux Linkages

Uses of Inductance

Inductance has three very important uses. In terms of inductance are expressed the self and mutual linkages of circuits, the self and mutually induced voltages, and the energy stored in the magnetic fields. The first two uses are apparent from treatments which have been given concerning the derivations of the quantities themselves. The third property is simply given here as the statement that the energy stored in the self-induced field of a circuit is related to the inductance and the current of that circuit, and the energy stored in the mutual field of two circuits is dependent upon the mutual inductance between the circuits and the currents of those circuits.

In alternating-current work a knowledge of inductance is vital to the solutions of such problems, and in treating machines the various inductances are all-important since the reactances derived therefrom must be definitely known in order that the performance of the machines can be calculated. The solution of transient direct-current circuit problems cannot be obtained if inductance is present and not quantitatively known. Practically all transient phenomena require a predetermination of the circuit inductance for their calculation.

Purpose and General Method of Test

Several coils had been previously tested by means of alternating current, and their inductances determined from direct measurements. That is, the ratio of the coil voltage to the coil current was the reactance in ohms (assuming resistance negligible) from which, knowing the frequency, the inductance was easily computed. It was desired, however, to check these readings by passing direct current through the coils and noting the deflections produced by a ballistic galvanometer as the circuit was altered to permit the current to gradually die away to zero, and with it the flux which that current had set up.

The coils were not portable, hence existing laboratory arrangements for such measurements could not be used and floor methods had to be devised. It was hoped, and it later turned out to be so, that the scheme used would be simple enough to be easily set up for general field or laboratory work, yet allow practical accuracy in the readings.

The general idea used in the testing procedure was to send current through the coil under observation, and then to suddenly short-circuit it. The generating source thus no longer embodied the coil as a part of its external circuit but simply sent current across the short branch. Also, the coil gradually discharged through a circuit in which there were no live voltages and the flux linkages completely died away to zero.

At the same instant that the coil was short-circuited, a ballistic galvanometer was connected across a part of that closed circuit. The e.m.f. applied to the instrument was thus the voltage drop across the small resistance between the terminals of the galvanometer circuit, and the total deflection registered by the ballistic galvanometer was proportional to the time integral of that small voltage.

It was decided to use a comparison method in obtaining the inductance of the coils since such a method would be a much simpler solution to the problem than that of determining the necessary data needed for a direct calculation. Accordingly, the inductance of a portable air-core solenoid of closely packed turns was obtained from the standardizing laboratory. After readings had been taken on the coils to be tested, they were replaced by the known inductance and deflections again read. With the circuit resistances and currents known in both cases, and with the inductances being in a manner proportional to the deflections, as will later be shown, the self-inductances of the tested coils were hence completely determined.

The Ballistic Galvanometer

A galvanometer is usually referred to as a device used in obtaining the strength of relatively weak currents by measuring the effects of the magnetic fields which those currents produce. The ballistic galvanometer is a measuring instrument of the moving-coil type and works upon the general galvanometer principle that a current carrying conductor has a force action upon it when placed in a magnetic field. The magnetic field is produced by stationary permanent magnets and hence is of constant value. The current-carrying conductors are the turns of the galvanometer coil which is suspended in the air gap between the magnetic poles and is free to rotate about its own axis, the restoring force being the turning moment of the suspension wire supporting the coil. A small mirror attached to the moving element redirects a beam of light thrown upon it to a scale, and the travel of the light ray over the scale indicates the amplitude of the coil deflections and hence the strength of the turning force given it.

The ballistic galvanometer, unlike usual instruments, is not designed to necessarily measure the effect of a steady current or even one in which the current changes slowly, but is primarily built to measure the quantity of electricity which transient currents of very short duration displace through a system. It measures the time integral of the current since

$$Q = \int idt \tag{8}$$

The moving part of the galvanometer is made comparatively heavy, *i.e.*, with a large moment of inertia, so that the coil will swing slowly and allow the transient current to have completely disappeared before its impulse is felt. Upon moving from rest the suspended element gives a sudden kick (ballistic is derived from the Greek word meaning "to throw") and then gradually falls back to its original position. Only the maximum deflection is recorded, this amplitude being proportional to the quantity of electricity which has passed through the coils.

The ballistic galvanometer is also designed for a relatively long period which varies from several seconds to many minutes, depending upon the type of work for which it is to be used. The galvanometer employed in this instance had a period of ten seconds which allowed the maximum deflections to always be conveniently determined and permitted the tested circuit to completely discharge before the galvanometer moved from rest. Moreover, the device was critically damped so that the coil did not oscillate about its zero position, but came smoothly and readily to rest. This feature was a considerable time saver in the many readings which were taken.

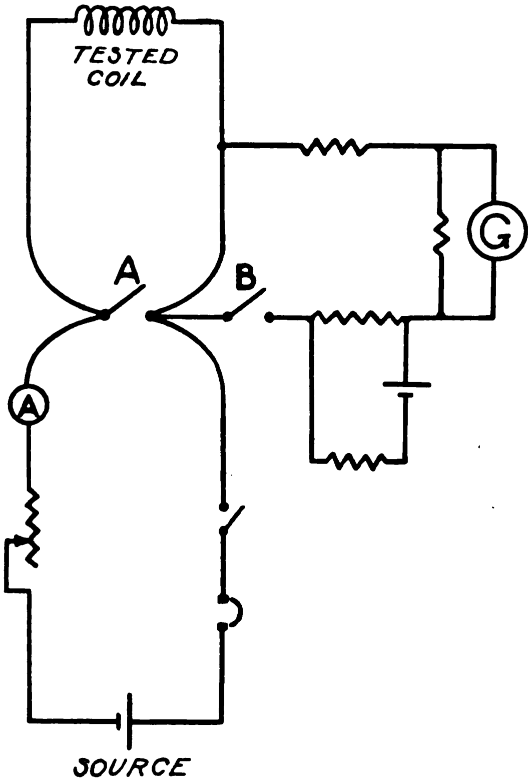

Fig. 4. The Connection Diagram for the Circuit Used in Determining the Self-inductance of Coils by the Use of a Ballistic Galvanometer

Circuit Diagram

The schematic diagram for the inductance measurement is given in Fig. 4. The direct-current source was a 125-volt general distribution system and supplied a current of about ten amperes to the coil to be tested. The variable resistance in the circuit served two purposes. It was first a means of initially adjusting the current through the coil, and secondly, it acted as a current-limiting device for the supply when the coil was finally short-circuited by switch *A*.

Upon closing switch *A* further current carried by the main portion of the circuit was diverted from the coil across the switch. The existing current in the tested circuit was thus allowed to slowly die away to zero through the inductance and the very low resistance of that path. The resistance of the switch was made neglible to the extent that any voltage drop across it was not sufficient to allow current to flow in the coil circuit and alter the galvanometer deflections in any way. Even a permanent deflection of a fraction of a millimeter on the scale was not detected, which with an instrument as sensitive as a ballistic galvanometer meant a completely satisfactory short-circuit for the coil.

The coil had an iron core; hence, for high values of current, saturation would exist and would therefore give different circuit inductances, depending upon the current used. Only the inductance of the non-saturated circuit was desired so the current was kept reasonably low. It should be pointed out here, though, that it is entirely within the limits of the apparatus described in this article to obtain an inductance-current curve for a magnetic circuit of variable permeability.

In order to determine the flux linkages of the coil it was necessary to measure the quantity of electricity which passed through the circuit after the coil was short-circuited. This was accomplished by connecting the galvanometer circuit across one of the leads between the switch and the coil. The voltage drop across the lead, being always directly proportional to the passing current, and being applied to the instrument, would permit this relative measurement of electricity. The galvanometer was shunted by a low resistance to effect critical damping, and a much higher resistance was placed in series with the apparatus to limit the current flow through the instrument so that fair deflections of about 200 millimeters were read on the scale.

Switch B in the galvanometer circuit was the second blade of a two-pole single-throw switch of which A was the first blade. This combination allowed both the coil and galvanometer circuits to be closed simultaneously. The results of the switch action, as registered by the oscillograph, are shown in Fig. 5. Curve a is the decay of current in the short-circuited coil, obtained by closing blade A of the switch, and Curve b is the current in a separate non-inductive system, closed by blade B and used simply for this trial test. It was observed from the 60-cycle timing wave that both blades snapped completely shut within 1/2000 second of each other. This short time interval allowed no appreciable change in the coil current, as shown by the oscillogram.

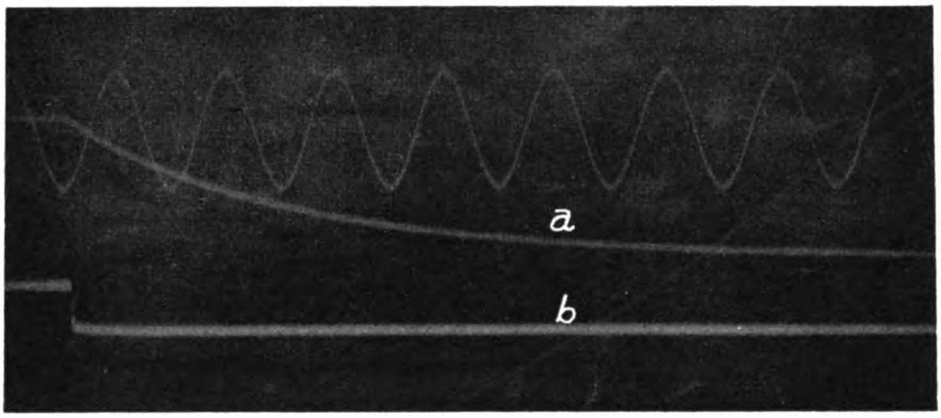

Fig. 5. Oscillogram Showing the Results of the Switch Action

Curve a—Blade A short-circuiting the tested coil
Curve b—Blade B in the galvanometer circuit

Difficulties Encountered

In conducting the tests, several difficulties were encountered. They are enumerated here for completeness of the general treatment of the laboratory work and for the value they may have in future uses of this testing method.

When the galvanometer was first set up, the needle swings were oscillatory and the time required for the light beam to come to rest was unduly long. To obviate this difficulty the instrument was shunted by a variable resistance box and the plugs interchanged until critical damping was obtained. The galvanometer then gave a pronounced kick when inserted in the circuit and fairly readily "crawled" back to rest. The particular point mentioned in this paragraph should not perhaps be regarded as a difficulty of the experiment since it exists with most galvanometers, but its recognition leads to the rapidity of making measurements.

One outstanding difficulty of rather surprising character was encountered in initially testing for the zero position of the galvanometer. It was found that the instrument gave a permanent deflection of considerable magnitude even with switch blade B open, showing that current was flowing through the tested coil. With the circuit breaker open, or with the galvanometer entirely disconnected, the light ray came back to its first setting. The trouble was traced to the composition base of fibrous material which was used for the switch, and it had to be changed for a switch having a porcelain base. The first switch, although supported by what is thought of as a non-conductor of the first order, permitted sufficient leakage current to pass over its surface to render galvanometer readings quite inaccurate. No trouble at all was experienced when the porcelain base switch was introduced.

Another source of error was found in the long leads running from the main circuit to the switch A. The original connection is shown in Fig. 6 in which the switch leads were fastened to the main leads by relatively long wires. With switch A closed, the voltage drop between points a and b was great enough to send some small fraction of an ampere through the tested coil and destroy zero readings on the galvanometer.

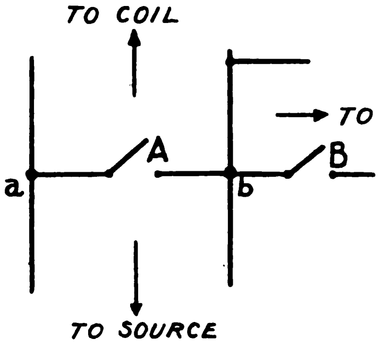

Fig. 6. Diagram Showing the Original Connections to Switch *A* and the Opportunity for a Comparatively Large Voltage Drop Between Points *a* and *b*

The leads from the coil and the source of supply were therefore brought directly to the switch as shown in Fig. 4.

Mechanical joints at the switch were first used and the leads simply clamped under the usual bolts for that purpose. But a form of puzzlement, and not so obvious, was the fact that an absolutely dead short-circuit across the tested coil did not yet exist and some small current flowed in the galvanometer circuit. To correct the difficulty it was found necessary to solder the switch leads to the blade and to the jaw of the switch. This procedure eliminated mechanical contacts and with them contact drops. It also excluded thermal voltage effects which existed to some extent at the contacts.

Along with the protection for constant zero readings, the final improvement in the switch connections was obtained by amalgamating the blade A and its jaw. The results were very beneficial. The contact resistance under that condition was as low as could possibly be made and no further difficulty was experienced with the main circuit connections.

Some thermal or contact voltage existed in the galvanometer lines and this effect had to be balanced out by adding a small corrective voltage to that circuit. This small e.m.f. was the voltage drop over a foot length of fine wire which in turn formed part of series circuit containing a low-voltage battery and a high resistance. The corrective circuit is also shown in Fig. 4. Such a method is commonly used to balance out thermal effects in a galvanometer circuit.

Observations

With a low current flowing through the main circuit and the tested coil, the switches were simultaneously closed by hand upon a signal from the person reading the galvanometer. It was found that a little difference was made in the time of closing the switches, although they were always snapped shut from about the same raised position and in the same manner. For work in which the closing time might ever be of importance, trigger action could be obtained by a stiff spring placed so as to pull the blade toward the jaw. From the same raised position the closing time of the switches would be practically unvarying.

Under the favorable conditions which were ultimately achieved the galvanometer consistently gave readings to an accuracy of about one or less parts in one hundred. But few trials were thus required for any one coil.

It was observed that it was not necessary for the light beam to reach zero on its return swing before another reading could be taken. If the ray came back to within a few divisions of its starting position the scale could be shifted to meet the light beam and a new reading taken. The maximum deflections were unaltered by this shift. The reason for such consistent deflections was of course the fact that the galvanometer had no appreciable motion when close to zero and a new impulse given it would be unaffected by a displacement of few millimeters as shown on the scale. As far as the new impulse was concerned the coil was practically at rest.

After readings were taken on the tested coil it was replaced by the standard coil of known inductance. Readings were then repeated on the standard inductance, and the inductance of the unknown coil determined by comparison of deflections. Both coils were tested for resistance, the resistive circuit including the leads from switch A to the coil connections as well as the coil itself.

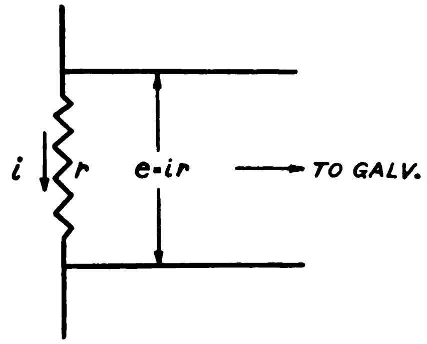

Fig. 7. Source of Impulse for Galvanometer

Calibration Constant

The theory of observation for the ballistic galvanometer is conveniently thought of in the following manner. The voltage drop applied to the galvanometer circuit is that caused by the current which flows in the discharging circuit and passes through the resistance wire between the instrument leads. Since the galvanometer coil does not move until the current has ceased flowing, it responds to the total voltage impulse given it, which is

$$\int e\,dt = r\int i\,dt = rQ \tag{9}$$

in which the quantities refer to the small resistance wire of the circuit shown in Fig. 7, Q being the quantity of electricity transmitted. The galvanometer then acts in a manner proportional to the total quantity of electricity transferred through the tested coil during the transient period.

Now as illustrated in Fig. 8,

$$Q = \int_0^\infty i\,dt = \int_0^\infty I\epsilon^{-\frac{R}{L}t}\,dt$$

$$= \frac{L}{R} I \qquad (10)$$

where L is the total inductance and R the total resistance of the discharging circuit, and I is the initial value of the current in that circuit. Hence the quantity of electricity is proportional to the time constant of the circuit as well as to the initial current.

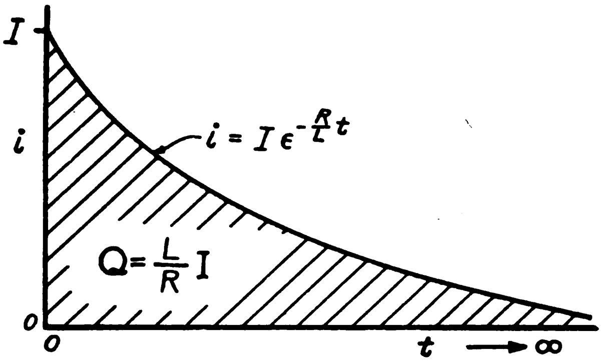

Fig. 8. The Transient Current Through the Galvanometer. The deflection of the instrument is proportional to the area integral of this curve

If the subscript 1 denote quantities pertaining to the coil under test, and the subscript 2 relate to the standard coil, then

$$\frac{d_1}{d_2} = \frac{Q_1}{Q_2} = \frac{L_1}{R_1} I_1 \times \frac{R_2}{L_2 I_2} \qquad (11)$$

whence the unknown inductance is

$$L_1 = \frac{d_1}{d_2} \, \frac{R_1}{R_2} \, \frac{I_2}{I_1} L_2 \qquad (12)$$

Of course L_2 can be expressed in henries, millihenries, or ohms reactance, and L_1 will then be accordingly named.

As an illustration of the manner of calculation, sample data for one coil and the standard inductance are given in the following tabulation:

Tested Coil	*Standard Coil*	
86-86-86.5-86	58-58.5-58-58.5	mm. deflection
0.1264	0.115	ohms resistance
12.1	12.05	amperes
L_1	1.25 mh.	inductance

From these data

$$L_1 = \frac{86.1}{58.25} \times \frac{0.1264}{0.115} \times \frac{12.05}{12.1} \times 1.25$$

$$= 2.025 \text{ millihenries inductance}$$

If the calibration constant be given the value

$$K = \frac{I_2 L_2}{d_2 R_2}$$

then the inductances of the tested coils are readily computed as

$$L_1 = K \frac{d_1 R_1}{I_1} \text{ millihenries}$$

Mutual Inductance Tests

The method described for determining the self-inductance of a coil was likewise successfully used to obtain the mutual effect between two coils, a measurement which was a trifle simpler to make. The power leads, instead of joining the tested coil circuit at switch A, were simply disconnected and applied directly to the primary of the new circuit. Switch A was left closed and the galvanometer circuit remained untouched.

The secondary was always a distinct closed circuit, hence either making or breaking the primary supply gave the same deflection on the galvanometer scale. Readings were thus secured with great ease and rapidity.

As before, the calibration was obtained from a knowledge of the deflection given by the standard coil under a self-inductive test. That is, the mutual inductance of the two tested coils was simply

$$M = K \frac{d_1 R_1}{I_1} \text{ millihenries}$$

where R_1 is the resistance of the secondary circuit; I_1 is now the current in the primary winding; and d_1 is the new deflection.

Conclusions

The results obtained by this laboratory method for the determination of inductance have been very successful, and once the apparatus was set up its manipulation involved but little time and effort. It is felt that the method is applicable to general laboratory testing since it is accurate and relatively simple to handle; and because of the portability of the circuit parts and the ballistic galvanometer, the method can also be used for field work.

Structural Materials for Switching Equipment

Trend Toward Metal Construction—Asbestos Intermediate Between Metal and Natural Materials—Slate, Marble, Concrete, Brick—Features of Each Material and of Available Finishes

By EMIL G. BERN
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PRACTICALLY parallel with the general change in machine design from cast-metal frame parts to structural steel—fabricated by the gas flame and the electric welder—has come into general use the metal switchboard, and apparently as sweeping has been the change. Several factors have been responsible for this transition: first, the general tendency towards safety-enclosed equipment, which eliminates the use of the panel as an insulating support for the apparatus; second, the economic pressure towards factory-built-complete equipment, which can be manufactured most favorably with special tools and which can be installed and put into service with the least time and effort.

With many possibilities brought within convenient reach by modern manufacturing methods, the definite answer to these demands was *metal construction*. But as the switching equipment of today is not only a switchboard, but a combination of apparatus that is electrically controlled and located in almost every corner of the power plant, the trend toward metal construction has been so general as to cover the entire field of switching equipment.

Metal Construction

Probably about the first metal switchboards used in this country were those manufactured by the General Electric Company during the early part of 1915 in connection with truck-type switching equipments. Since then the evolution has been sometimes gradual and sometimes by leaps and bounds. The advantages of steel as a panel material were evident from the beginning, although the transition period is usually long when it concerns equipments that grow by extension to existing installations.

The saving in weight, which in cases of simple panels amounts to about 75 per cent, is an item well worth considering from the standpoint of handling and installation, as well as that of packing and shipment. Structures of the older design required a heavy frame for supporting the natural stone panels in shipment and handling. Considering the panels, as well as the entire structure, the modern metal construction is also much more compact.

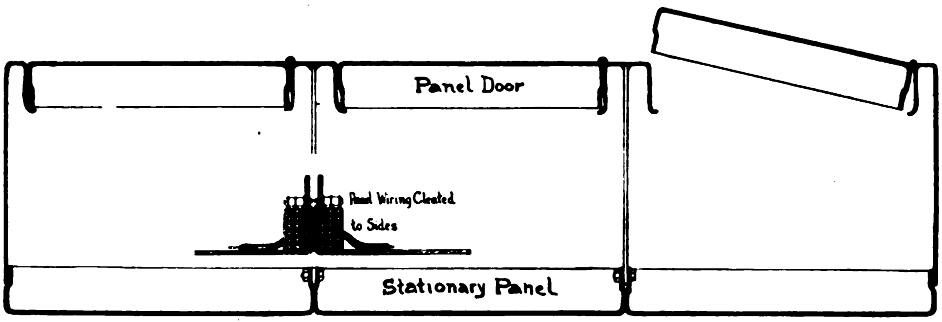


Fig. 1. Schematic Plan View of a Three-unit Central-station Control Board of Steel. Note cleated wiring at sides

While the tendency at first was to bolt or weld the panels to a frame of structural steel, the bent construction is now almost universally adopted. In this new type of construction, the steel-plate container is bent or formed so as to serve as its own supporting structure, frequently with little or no increase in thickness.

Fig. 1 illustrates this point by a plan view of a three-unit central-station control board of steel. Here the front panels, which provide a necessary display surface for the instrument and control equipment, are built and shipped in one structure integral with the hinged metal panels which serve to support the maintenance equipment, such as integrating meters, graphic meters, relays, calibrating and testing equipment, etc. No structural shapes are required in this construction. The plate material is made of cold-rolled sheet steel 0.156 in. thick which has been stretched slightly to remove the waves. As a modest embellishment a drawn sheet-steel molding is sometimes used at the top as shown in Fig. 2.

The hinged-panel design was introduced to obtain maximum compactness; it provides access to the interior of the structure in lieu of the conventional passageway at the rear of a board.

A compact control bench of sheet steel, also built and wired complete at the factory, is shown in Fig. 3.

The finish of these switchboards is usually dull black to follow the practice that for many years has been conventional with slate panels. After the steel surface has been freed from grease and oil, a priming coat of good adhering quality is applied. A filler, if necessary, is then used and rubbed down; and the final finish consists of one or more coats of dull-black pyroxylin lacquer. Refinishing on account of alterations or repair is very simple.

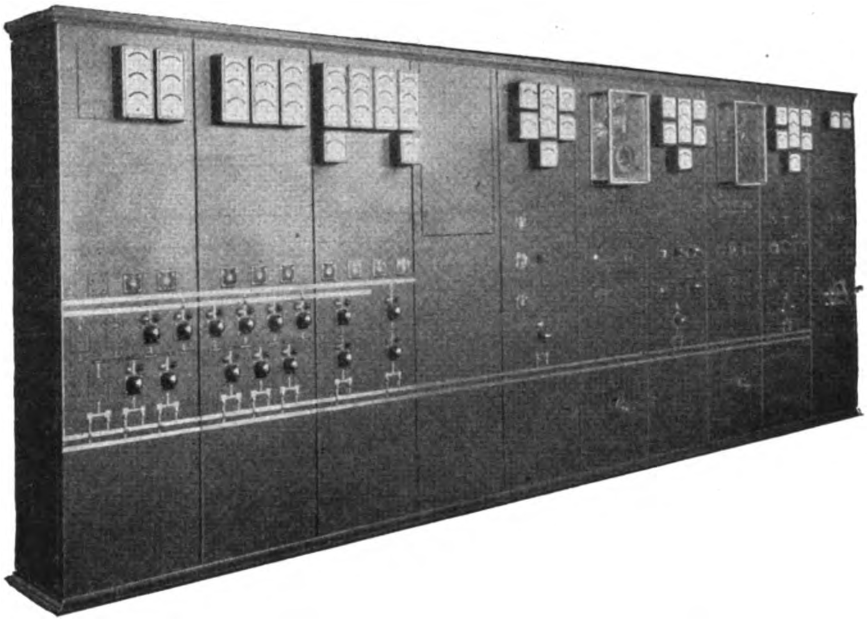


Fig. 2. Metal Switchboard for Modern Central-station Control

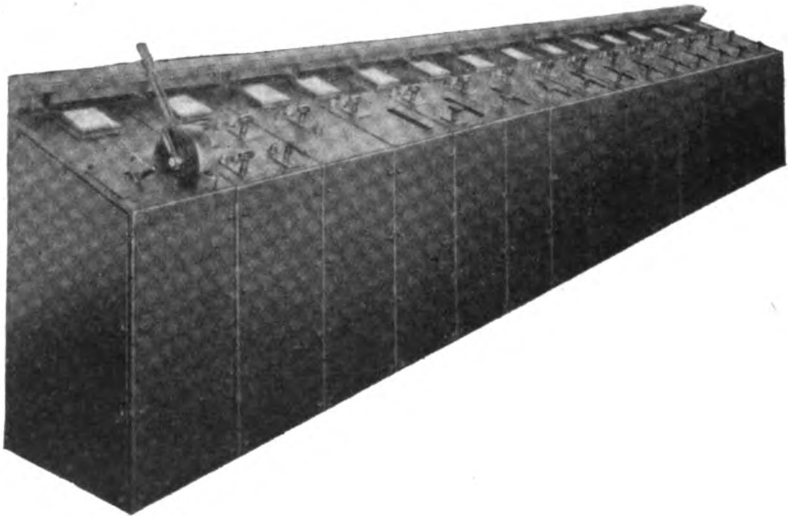


Fig. 3. Control Bench for Steel Mill, Built of Sheet Steel and Wired Complete at the Factory

Asbestos Panels

Where insulating quality is required, ebony asbestos may be said to be the companion material to steel panels because of its similar finish which permits the use of the same materials for refinishing. Furthermore, ebony asbestos has a certain resiliency which is an advantage in handling or shipping assembled structures. As an independent panel material, it possesses somewhat greater mechanical and dielectric strength than slate or marble. Its weight is about one-third less than either of these other two materials.

The material most commonly used consists of asbestos fibres molded with Portland cement into large slabs. After these slabs have been thoroughly cured in a flat position, they are impregnated, cut, and finished as required. The cutting, bevelling, and drilling operations are about the same as with slate, but require somewhat different tools and speed.

Its greater resiliency, which is an important quality in its favor, must however be given proper consideration in providing supports of adequate stiffness. For some kinds of apparatus this is extremely important.

As with steel panels, the surface is usually given a finish of dull-black pyroxylin lacquer. Finger marks, oil, or grease spots may be removed by soap and water, or by carbon tetrachloride. Oiling is not advisable because of its tendency to support dust on the surface, and to remove the dust might require that the surface be rubbed with a rag, which operation would likely produce a surface polish.

Natural Black Slate

When the quarries at Monson (Me.) were opened, and were able to turn out a reasonable quantity of natural black slate of suitable electrical qualities free from metallic veins, and of a close and uniform texture, this material was immediately adopted in the better grades of switchboards. This was before the days of synthetic materials. The Monson slate is less porous than other grades—in fact, practically non-porous; it requires no paint or filler to protect it against absorption of moisture due to surface condensation. It can, however, hold on the surface a small amount of oil which gives it a very pleasing soft-black appearance that will not be marred by finger marks or small surface scratches. The material is a homogeneous product; hence any surface damages that may occur during shipment, installation, or later can easily be rubbed down until obliterated, and a simple application of light mineral oil on the surface restores the black color. This slate will not take a polish even if rubbed and cleaned repeatedly with a rag. As the oil does not affect the finish of the equipment, it can be applied without any special care, but no more should be used than can be absorbed. Dependent largely on local conditions, the oil gradually disappears and the surface may then be refreshed by another application. In this manner a natural black slate switchboard is always maintained at its best.

The cleavage in quarried slate appears as a fine grain, in some respects similar to the grain in wood. While a greater uniformity may be claimed for the artificial finish, the grain gives a live appearance to the surface; and the natural beauty in the grain of slate is as pleasing in effect as that in a piece of fine woodwork, which, because of this very quality, one is reluctant to cover with paint.

On account of this feature it is important when ordering slate panels to have the grain run in the same direction. The quarries understand this and will make provision to cut or select the slate accordingly if care has been taken to specify the vertical as the first of the three dimensions.

This slate has greater stiffness than asbestos-panel material but less resiliency, and is not quite so good in dielectric strength.

Marine-finished Slate

In order to obtain a uniformly black surface and conceal the natural grain of the slate, an artificial finish is sometimes applied over the surface after the panels have been drilled. The slate so finished usually goes under the name of Marine-finished Slate or Dull-black Finished Slate. The material most commonly used for such a finish is a marine lacquer with aniline dye and a very small amount of carbon black. This finish will closely match a switchboard of marble which has been refinished in dull black; and also switchboards built of ebony asbestos. In some cases a lacquer finish has been used advantageously on some grades of slate that are not uniformly black, and sometimes for sealing a porous surface. For electrical purposes such slate may be of satisfactory quality if of adequate dielectric strength and after being baked and sealed against moisture with this lacquer finish.

Black-enameled Slate

Black-enameled slate came into vogue as a standard switchboard material before the days of the Monson slate. It was considered to be free from some of the objections found in marble, and at the same time its black luster presented a fairly pleasing appearance. Any grade of good insulating slate could be used regardless of its color, which was frequently a spotted green or pink. This finish was produced by a coat of black japan baked over night in a temperature of about 260 deg. F. After cooling, it was rubbed down with pumice stone. Another coat of black baking japan was then applied and baked as before; after which the surface was rubbed down again and polished, finally with the palm of the hand. The panel was usually drilled before the enameling process to avoid scratching the high gloss finish.

Black-enameled slate was a rival to marble for a number of years in high-grade switchboard installations. However, it was rarely possible to ship and install such a board without injury to the original finish; and damage to the surface, during installation or afterward, could seldom be repaired without dismantling the panel and returning it to the factory. Furthermore, the high-gloss black finish became tiresome to the eyes of operators on large switchboards.

Lately, however, with the development of the newer air-drying lacquers, it has been found possible and more satisfactory to produce this finish by an air-drying process. This simplifies and quickens production, permits repairs to be made without difficulty, and matches exactly the previous baked finish. This same air-drying finish may now be applied to ebony asbestos panels as well as to slate panels, so that the benefits of increased mechanical and dielectric strength can be obtained.

This process has been mentioned merely to record a finish that is still available where the feature of high gloss is desired for decorative purposes, or for extending present installations.

Marble

Blue Vermont Marble was perhaps the first switchboard material to supersede the wooden skeleton board. The reason is easily traced to the availability of this material in the architectural field, to its fair dielectric strength, and to its pleasing appearance.

Difficulty in keeping marble free from oil and grease was one of the first objections brought against its use, and a very serious one. This is still an important consideration, but during recent years means have been found for cleaning marble in a fairly satisfactory manner.

The mechanical and dielectric strengths of marble were usually sufficient for the low voltage and comparatively light equipment then in use. Even today it would be difficult to find another material possessing the pleasing architectural effect of marble. Its almost infinite varieties in color, shade, figure, and texture offer unusual opportunities for appropriate expression. Many possibilities lie in the use of marble panels ranging from pure white to blue, green, pink, gray, and other tints in clouded or striped patterns and in different intensities of color.

Age has a softening or mellowing effect on the color of marble as on a structure of limestone; a process which is greatly accelerated by heat and light because the coloring matter in marble is usually of a vegetable nature. When a marble panel is selected for architectural effect, it is well to bear this mellowing tendency in mind for the switchboard may be exposed to considerable light and heat. Future extensions to equipments have also a bearing on this point, for the ageing effect greatly augments the difficulty of matching one piece of a natural product with another, especially those from different geographical locations. The only choice in matching lies in selection, and this with lapse of time and consequent change in cutting locations becomes a difficult matter. This problem is even more complicated today because only a small amount of the material is now used and available for selection; yet in spite of this, those who specify marble today do so almost entirely for esthetic reasons and naturally require the best selection. It should therefore be borne in mind that marble switchboards must be furnished complete in one selection from the quarry; it then becomes necessary to use the utmost care to avoid breakage of any slab in shipment, manufacture, or afterwards.

Another feature militating against the use of marble is its poor and erratic mechanical strength. Here again it is a matter for selection from a large stock of panels on hand, which due to small demands is not available today. Also, it is usually found that marble panels for extension do not have the same mechanical strength as those of the original installation.

Mason Work

As already stated, the switching equipment of today extends into every corner of the station and frequently embraces compartments for bus connections as well as switching apparatus.

For supporting indoor switching apparatus of medium high potentials, concrete cells and compartments have been used extensively up to this day of steel construction. The most important work in connection with concrete structures is the execution of the forms. If these be not true, the concrete will be misshapen and difficulty will be experienced when installing the equipment for it will not fit without changes or expensive adjustments.

On account of the high strength required, the narrow cross-sections necessary, and the smooth surface desired, a concrete rich in cement should be used. The concrete mixture best suited for this work is about one part of cement, two parts of fine aggregate, and three parts of coarse aggregate. Portland cement that meets the standard requirements of the American Society for Testing Materials should be used.

The coarse aggregate should consist of crushed stone, gravel, air-cooled blast-furnace slag, or other approved inert materials with similar characteristics. It should be composed of hard, strong, and durable particles free from injurious amounts of soft, friable, and thin elongated pieces, alkali, and organic or other harmful matter. The maximum size of the aggregate for walls and barriers more than three inches thick should be such that it will pass a one-inch screen, but should not be less than one-half inch. Not more than five per cent should pass a quarter-inch screen. For shelves and barriers thinner than three inches, the aggregate should be smaller and should pass a screen with one-half inch openings.

The water for concrete should be clear and free from oil, acid, alkali, organic matter, or other deleterious substances. It should preferably be equal in all physical and chemical properties to potable water. The strength of concrete varies with the amount of mixing water used. Five and one-half to six gallons of mixing water per sack of cement is approximately the correct quantity for constructing concrete bus compartments. More than this amount reduces the strength.

The concrete should be mixed in a batch mixer for at least one minute after all the materials, including the mixing water, are in the drum. When concrete is mixed by hand it should be on a water-tight platform. The cement and fine aggregate should first be mixed dry, being turned over until a mixture of uniform color is obtained. The coarse aggregate should then be added, and the whole mass turned at least three times to a uniform mixture. Next, the water should be put into the batch and the entire mixture turned again at least three times, or until a homogeneous mass of the required consistency is obtained.

Care should be taken in placing the concrete to see that it is thoroughly worked around the reinforcing rods and that the faces of the concrete are well spaded. This will insure a good bond to the steel and will keep the exposed surfaces free from stone pockets. For thin walls or portions of the forms where the use of a spade is impractical, the concrete should be forced into place by tapping or hammering the forms.

Reinforcing rods, which are used very extensively to give additional strength to concrete structures, should be used with extreme caution in building switch and bus compartments. They may be used without hesitation in the foundation and substructure where they are most needed, but their use is not desirable for switch cells

Compartments with shelves either of soapstone or precast concrete are simpler to build than those of monolithic construction. The difficulty in the use of reinforcing bars is overcome by employing precast units. Experienced men for supervision of this work are not so essential as for the monolithic type of construction.

For concrete structures in an unheated station, joints are needed every 40 or 50 ft. to prevent cracking due to expansion and contraction. The joints should be constructed with a key or notch and with several thicknesses of tarred felt between the sections. All expansion joints should be carried through the foundation and no reinforcing steel should be allowed to extend across a joint.

The forms should be built of dressed and matched lumber at least ⅞ in. thick, thoroughly braced in all directions exposed to the pressure of the concrete. Before the concrete is placed, the inside of the form should be brushed once or twice with crude oil or soft soap to prevent sticking. An even better method is to use paraffine wax dissolved in kerosene. It is advisable to design the forms so that they can be taken down without wrecking. In addition to the advantage of saving the forms, this permits of their earlier removal, and allows the surface of the concrete to be rubbed down without much effort.

By rubbing down the surface of a concrete structure before it has become too hard, a smooth finish can be obtained by very little work. After it has hardened, it may be rubbed down with carborundum blocks, but at greater effort.

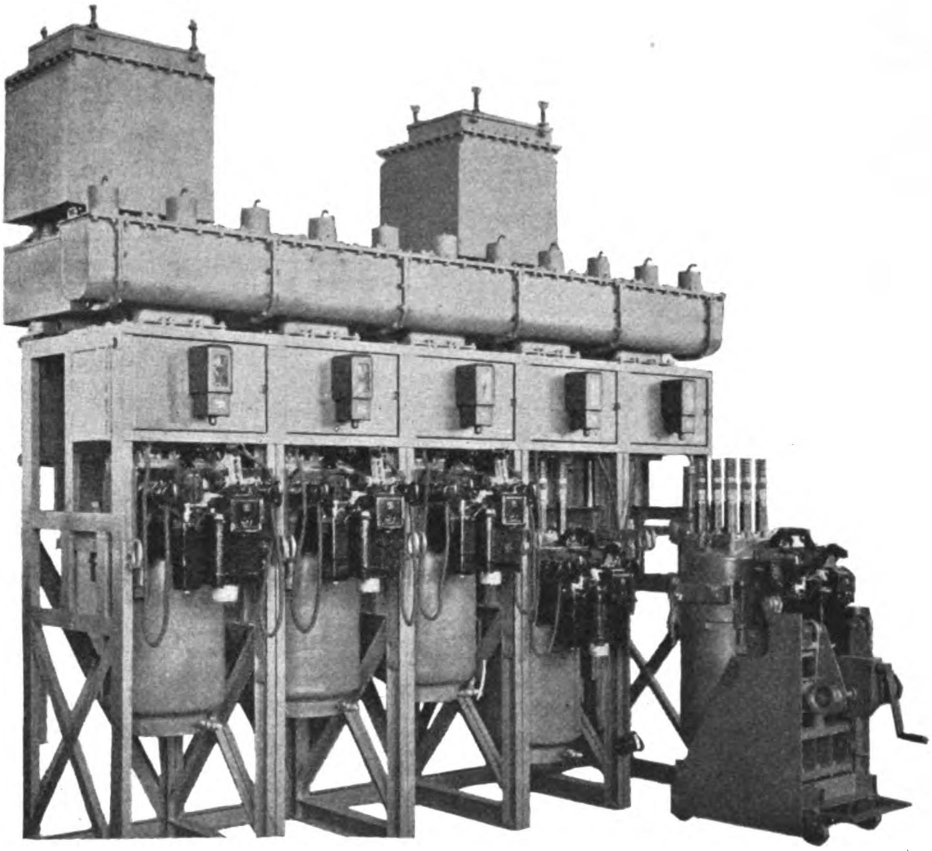


Fig. 4. A Modern 15,000-volt Metal-clad Switching Equipment, Factory-built-complete which Has to a Large Extent Superseded Masonry Construction

It is often desirable to paint concrete structures for appearance and to maintain them in cleaner condition. Care should be taken to avoid the use of strong metallic paint for high-potential compartments and cells. Linseed oil paint will not permanently adhere to a concrete structure without the previous application of some solution for neutralizing the action of the alkali in the cement, which has a tendency to saponify linseed oil. A solution made by mixing one pound of zinc sulphate with one gallon of water is often recommended for washing the structure to prepare it for the paint. It may be sprayed or brushed as seems most convenient. The same class of paints as used on wood may be used successfully on cement some time after application of the neutralizing wash. This may be either interior flat wall paint of any color for a flat finish, or interior gloss paint where a gloss surface is desired. The pores should not be sealed before the concrete surface is dry.

Quick-hardening Cement

The time taken for concrete structures to harden so that the forms may be taken down and the equipment bolted in place is often a serious item of delay in installation work. For conditions where the extra cost is warranted by a saving in time, a quick-hardening cement may be used advantageously. This material behaves similarly to Portland cement, except that it reaches a strength after twenty-four hours at least equal to that of Portland cement after months of ageing.

In using this cement the same proportions of sand and coarse aggregate may be employed as with Portland cement. Two things must, however, receive very careful consideration. First, sufficient water should be sprayed on the structure during the curing period, else the strength will not approach its normal value. Second, the forms must be varnished, or treated in some equally efficient manner, to prevent absorption of moisture from the concrete, otherwise the surface will be weak. Metal forms are far superior to wooden forms for this kind of concrete.

Brick Structures

Under certain conditions, bricks are preferred for cells and bus compartments in place of concrete. While control conduits, anchor bolts, and inserts are somewhat harder to take care of, there are compensating advantages. Shelves are then usually made of precast concrete, or of soapstone, and the walls and barriers are made of some kind of brick in keeping with the character of the building. The bricks should be set in a mortar consisting of two parts of best quality Portland cement and six parts clean, sharp, screened sand. To this should be added, after mixing, one-half part lime putty which has been made from newly slacked lime and allowed to settle.

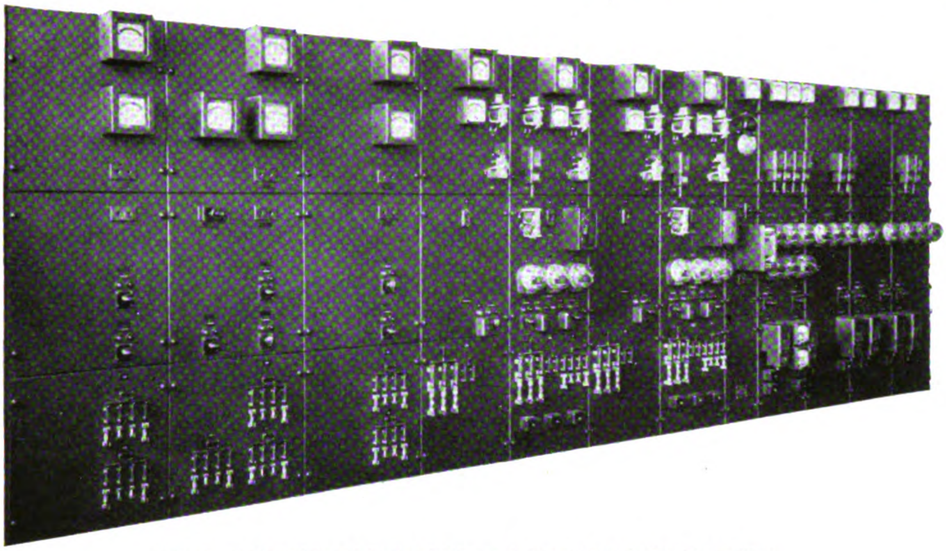
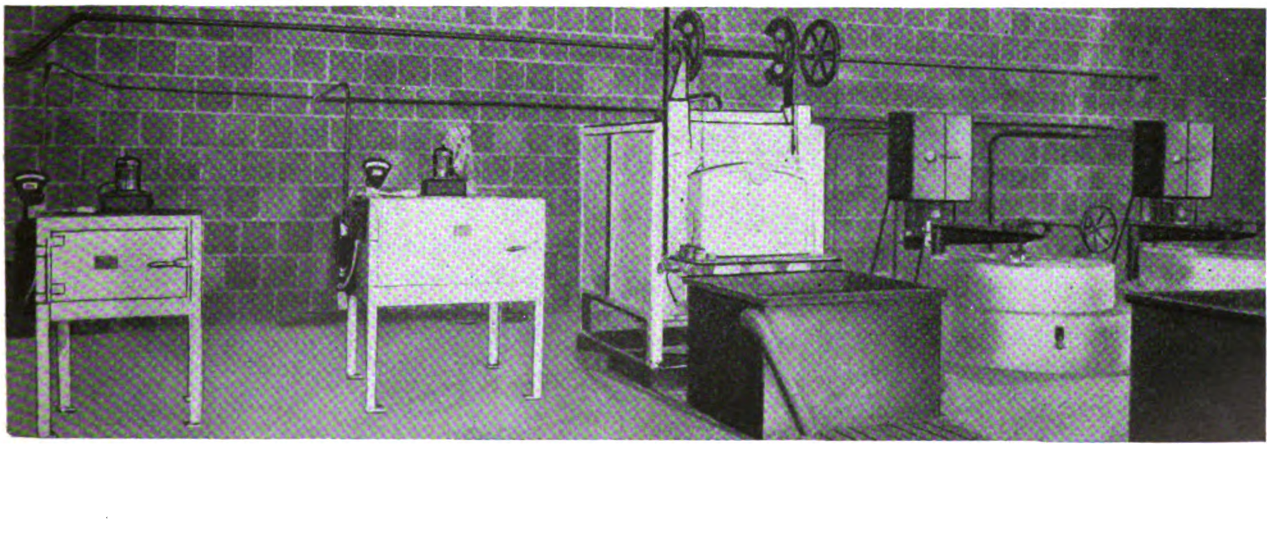


Fig. 5. A Switchboard Built of Ebony Asbestos Panels for Controlling Railway Mercury Arc Rectifiers

Electric Furnaces for Heat-treating Ball Bearings



A 35,000-kw. Synchronous-synchronous Frequency Converter

Requirements of the System—Description of Units of the Installation—Ventilating System for Machines—Features of Design and Manufacture—Installation and Performance

By I. A. TERRY
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THIS article describes the salient features of a 35,000-kw. synchronous-synchronous frequency converter manufactured by the General Electric Company, and installed in the Acme Station of the Toledo Edison Company, Toledo, Ohio, through Henry L. Doherty and Company of New York City. The frequency converter is used to tie together the 25 and 60-cycle systems of the Toledo Edison Company and accomplish the following results: to make available for either system the generating equipment now installed; to effect better voltage stabilization during times of system disturbances; to obtain more effective relaying as a result of having, in effect, a greater generating capacity available on both 25 and 60-cycle systems; and to displace several small frequency changers, located at various points of the system, which proved to be very unstable during times of system disturbances and which had lower efficiencies than the efficiency of the new set.

*The frequency converter described in this article was placed in operation last November. In addition to filling its normal purpose of furnishing an energy transfer between the two systems to which it is connected, it has successfully held them together at all times, including several occasions when large system disturbances took place. The compact and symmetrical arrangement of the units and the totally enclosing features give the set an attractive appearance.—*EDITOR

The total generating capacity of the 25-cycle system is 90,000 kw. The load is almost exclusively power, although a slight proportion goes into lighting circuits. The power load consists chiefly of substations for furnishing direct current to railway and Edison systems.

The 60-cycle sources of power are the 50,000 kw. steam turbine capacity of the Toledo Edison System, 20,000 kw. located in an industrial plant, and a 30,000-kw. demand tie to the major interconnected pool of power in Ohio. The 60-cycle system supplies general power and lighting load, with a small amount of power diverted to the direct-current Edison systems.

A typical week-day load curve of the 25 and 60-cycle systems and the sum of the two is shown in Fig. 1.

General Description of the Set

The frequency converter is a five-unit four-bearing set, each main unit being supported between two bearings. The synchronous motor is rated 24-pole 46,000-kv-a. (48,000-hp.) 3-phase 60-cycle 300-r.p.m. 0.80-p-f. (overexcited) 13,500 volts. The excitation for the synchronous motor is furnished by a 195-kw. 250-volt compound-wound direct-connected exciter which is overhung on a stub shaft bolted to the motor shaft outside of the motor outboard bearing.

The synchronous generator is rated 10-pole 41,176-kv-a. (35,000-kw.) 3-phase 25-cycle 300-r.p.m. 0.85-p-f. (overexcited) 6750 volts. The induction starting motor and the direct-current exciter for supplying the generator excitation are both overhung on a stub shaft coupled to the generator shaft outside of the generator outboard bearing. The 10-pole induction starting motor has an intermittent rating of 1600-hp. 3-phase 25-cycle 375-r.p.m. (synchronous speed) 6750 volts. The generator exciter is an exact duplicate of the exciter for the synchronous motor except that it is rated 155 kw. 250 volts to correspond with the excitation required by the generator.

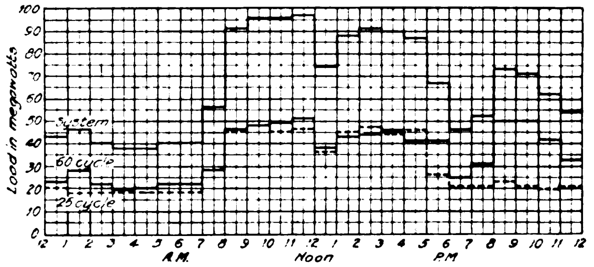

Fig. 1. Typical Week-day Load Curve of Toledo Edison System

The two main units of the set are coupled together by means of a forged half coupling on each shaft.

Fig. 2 is from a photograph of the installation. The synchronous motor is at the left, the synchronous generator is in the central portion, and the induction starting motor and synchronous generator exciter are at the right.

Fig. 3 shows, in outline form, the chief dimensions of the set.

The weight of the complete set is approximately 560 tons. The rotating field of the synchronous motor weighs approximately 146 tons and the armature (or stator) approximately 82 tons. The corresponding weights of the synchronous generator are 131 tons for rotor and 104 tons for the stator.

Ventilation System

All of the units of the set are of the self-ventilating type. Each main unit is enclosed in a recirculating system, the air being taken in through chutes at each end from the coolers located directly below; the warm air is discharged into the coolers through an opening at the bottom of each frame. Fans have been mounted on the rotors to increase the developed pressure to a value sufficient to circulate the required ventilating air through the machines and the coolers. The synchronous motor requires for ventilation approximately 80,000 cu. ft. of air per min. at an ambient temperature of 40 deg. C. and the synchronous generator requires approximately 65,000 cu. ft. of air per min.

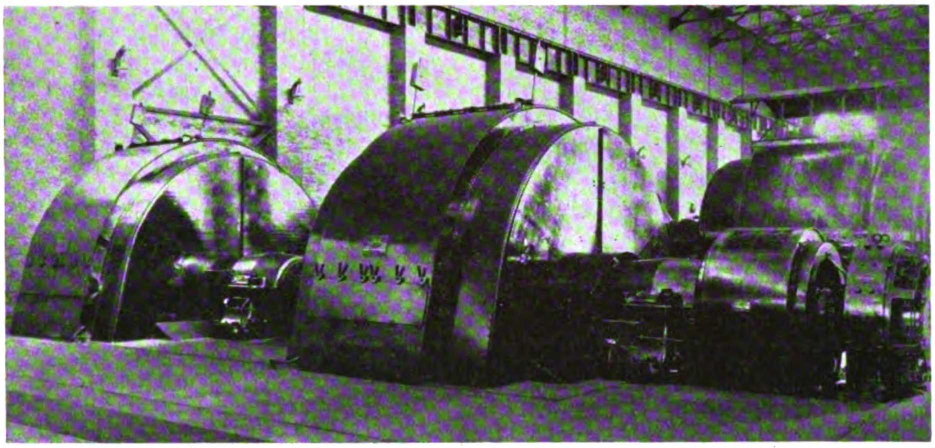

Fig. 2. General View of the 35,000-kw. Frequency Converter Installation at the Acme Plant of the Toledo Edison Company

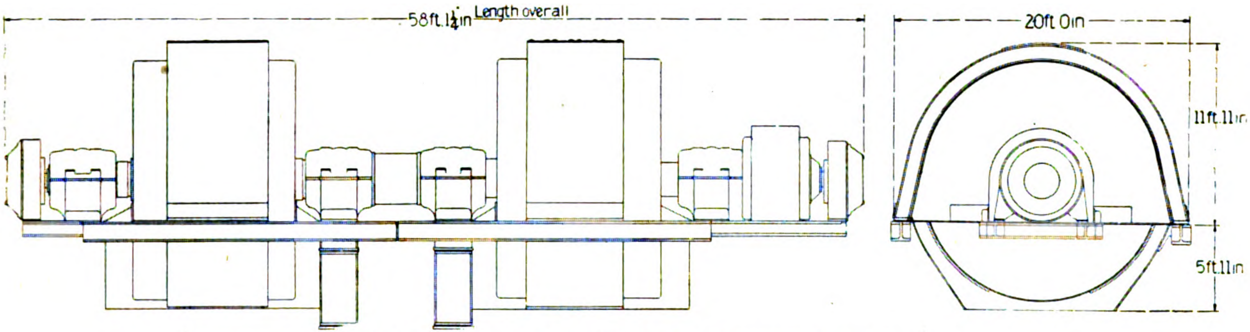

Fig. 3. Outline Drawing of 35,000-kw. Frequency Converter

The ventilating air is cooled by a combined spray and film cooler manufactured according to specifications of Henry L. Doherty and Company. In this system water is sprayed into the ventilating air just before it enters baffles opening into the end bells of the machines. This water falls onto a vertical column of tile piping through which the air passes. The amount of water entering the coolers is controllable by means of inlet valves.

Emergency covers have been provided in the stator frames, above the base line, to permit changing the ventilation to take cool air in from the basement through inlets provided in the coolers and discharge the warm air directly into the room. There are three openings in each frame, one on each side just above the base, and one on top of the frame. These covers and inlets to the coolers have been so constructed that they can be opened quickly if occasion should demand and are large enough to permit successful continuous operation of the set with this method of ventilation.

The exciters and induction starting motor take the ventilating air in from, and discharge directly into, the station.

Electrical Features

The normal operation of the set is converting 60-cycle power to 25-cycle power in accordance with the rating given previously. Normal reversed operation is converting power from the 25-cycle system with 41,176 kv-a. input at 0.87 p-f. (overexcited) to 45,333 kv-a. (34,000 kw.) at 0.75 p-f. on the 60-cycle system.

Increased power flow in either direction can be obtained by increasing the power-factor.

Each unit, when operating as a motor at rated excitation, is capable of driving the other unit as a generator at rated excitation and output without either unit exceeding observable temperature rises of 60 deg. C. (above a 40-deg. C. ambient) on the stator as measured by imbedded resistance temperature detector, or a rise of 80 deg. C. on the rotor as measured by change in resistance.

When operating as a frequency converter, the machines are designed to successfully stand either 150 per cent load for one minute or momentary reduction in terminal voltage not exceeding 50 per cent, but not both conditions simultaneously, without falling out of step or having the resulting stresses exceed safe values.

The 60-cycle unit has a condenser capacity of 39,000 kv-a., reactive leading. The corresponding capacity of the 25-cycle unit is 34,000-kv-a., reactive leading. Both of these capacities are obtained without exceeding the temperature rises stated. In case continued condenser operation of either unit is desired, the units may be uncoupled to permit either being run singly, thus eliminating the windage and friction of one machine from the condenser losses.

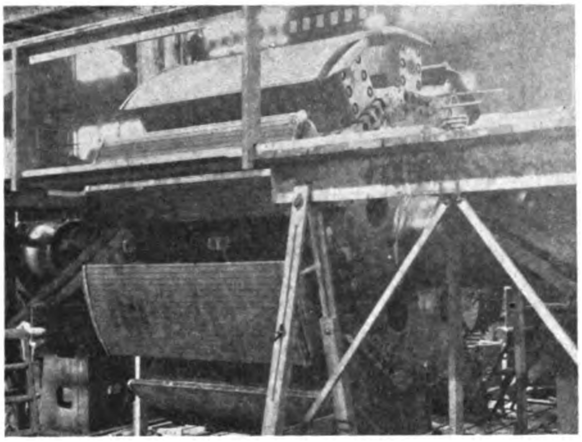

Fig. 4. Unwound Rotating Field of the 25-cycle 6750-volt Synchronous Generator

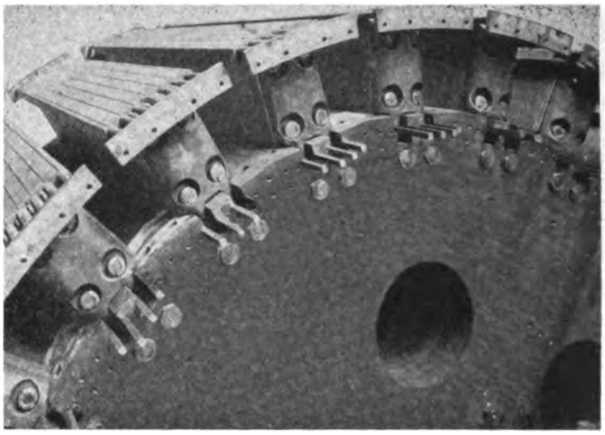

Fig. 5. Unwound Rotating Field of 60-cycle 13,500-volt Synchronous Motor •

The armature or stator windings of both units have Class A insulation, as defined by the A.I.E.E. Standards. The field or rotor windings have Class B insulation, as defined by the same reference. The armature winding of the 60-cycle unit is of the transposed-bar one-turn type with two coil sides per slot. Every strand is completely transposed from the bottom to the top and back to the bottom in the length of the slot to reduce to a minimum the strand and circulating loss. The insulation around each coil is all mica both on the slot and end portion. The armature winding of the 25-cycle unit is of the usual machine-wound type. To minimize the circulating loss, one turn in each coil is inverted to equalize the voltage generated in the top and bottom strands of the conductor.

The field or rotor windings of both machines are of edgewise-wound copper strip with nonferrous asbestos between turns, mica insulation around the pole body, and impregnated top and bottom pole insulating collars. The turns are extended at the ends of each pole to increase the effective surface exposed to the ventilating air.

The normal method of starting the set is by means of the induction starting motor. However, the 60-cycle machine has been provided with an amortisseur winding to permit starting the set by means of a compensator excited by the 60-cycle system. Starting from the 60-cycle system, of course, will be necessary in case of operation of the 60-cycle unit as a condenser uncoupled from the 25-cycle machine.

Individual forced oil starting pumps with 220-volt 25-cycle 1500-r.p.m. induction driving motors are provided for each bearing. The individual pumps for each bearing eliminate the necessity of an elaborate arrangement of piping of oil two ways between each bearing and a centralized pump location. The required pressure for each bearing is also obtained. The simplicity of this scheme is indicated in the frontispiece and in Figs. 2 and 8, where the pump and motor are shown at the base level on each bearing pedestal.

The normal starting operation of the set is as follows: The forced-oil starting pumps are run to provide a film of oil between the journals and the bearings, which greatly reduces the starting friction. This permits starting the set with a high resistance in the secondary of the starting motor, reducing the inrush kv-a. to a minimum. Normal voltage is applied to the starting motor stator terminals and the set started. The forced-oil pumps are then shut down as the oil film is maintained by the rotation of the journals. Undercurrent relays are set so that the secondary resistance is automatically decreased each time the stator current of the starting motor becomes less than 170 per cent normal, or 220 amp. There are five steps in the secondary resistance. The set attains synchronous speed (300 r.p.m.) in approximately four minutes. The starting motor synchronous speed being 375 r.p.m., the synchronizing operation is to bring the set to a speed above 300 r.p.m. and excite the unit to be synchronized to line voltage, then as the speed decreases to 300 r.p.m. and when the correct phase relation is assumed, the unit is connected to the lines.

Manufacture and Assembly of Set

Special attention was given to the design and construction of the set to facilitate assembly at the station. The maximum size and weight that it is permissible to ship by railroad made it impossible to ship the rotors and stators of the main units completely assembled.

The rotor spider of the 10-pole unit was shipped with the shaft in place and part of the field poles assembled. The rotor spider of the 24-pole unit was shipped with the shaft in place, but no poles assembled. Fig. 4 shows the 10-pole rotor assembled at the factory without the field coils. Fig. 5 is a similar picture of the 24-pole rotor. Both of these illustrations indicate very clearly the method of securing the rotor poles to the rotor spider by means of dovetails and keys. The circular holes in the rotor spider are made to reduce rotor weight and improve the ventilation.

The end plates of the pole pieces for clamping the rotor poles and for the additional function of supporting that part of the field winding which extends beyond the pole tips are shown in Figs. 4 and 5. The different types of amortisseur windings on the two units are also evident from these photographs. The 10-pole unit has an amortisseur winding without connections between poles and is complete as shown in Fig. 4. In this type of winding the amortisseur winding bars are silver-soldered to a low-resistance segment which extends across the arc of the pole face. The segments are supported by the bars.

The 24-pole unit has an amortisseur winding with connection between poles. The bars are silver-soldered to the low-resistance end segments, and then a one-piece steel ring, cut from a solid plate to avoid any weld, is bolted to the segments. This steel ring carries the current in part of the path between poles.

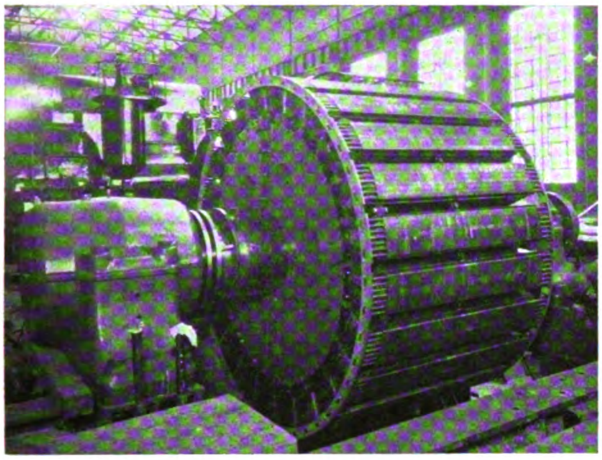

Fig. 6. View of Synchronous Motor Rotating Field. Preliminary line-up at installation

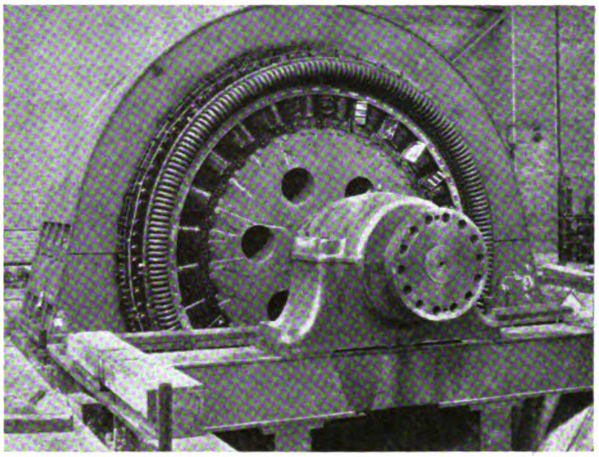

Fig. 7. Assembled Stator and Rotor of Synchronous Motor of 35,000-kw. Frequency Converter at Installation

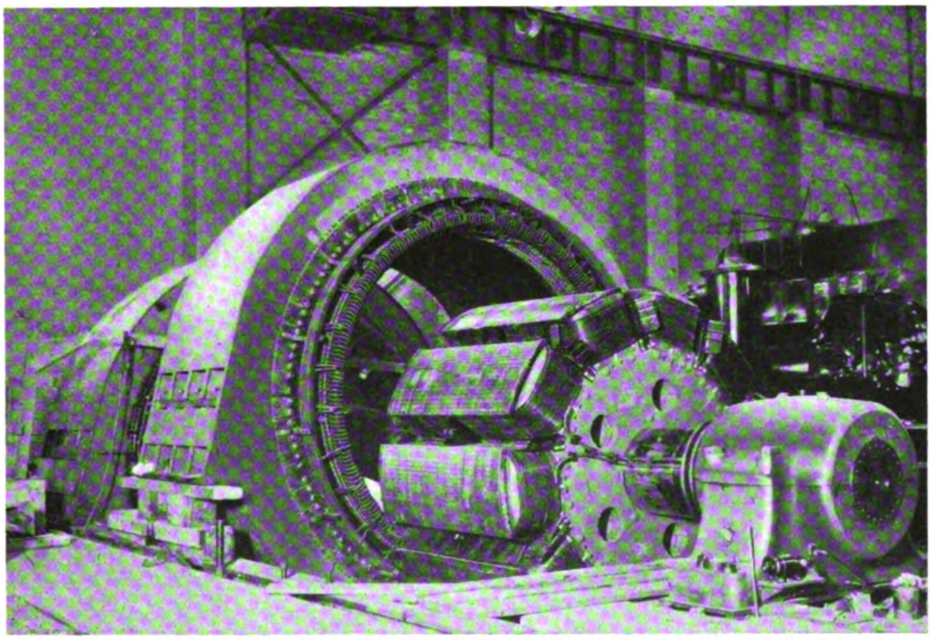

Fig. 8. Installation of 35,000-kw. Frequency Converter, Showing Method of Assembly of Generator with the Synchronous Motor in Place

The stator frames, too large to ship assembled, were split along a horizontal center line to be within clearance limits. The stator punchings were stacked at installation in the plant, after which the coils, which were formed at the factory, were put into the slots.

The steps in the assembly of the set at the Acme Station can be followed pictorially in Figs. 6 to 8 inclusive. The side rails forming the base on which the stators are supported and the outboard bearing subbases were secured in place. The subbase for the 24-pole unit inside bearing was assembled on the supports, and the 24-pole rotor assembled in its bearings for a preliminary check on alignment. This stage of assembly is shown in Fig. 6. The preliminary check being satisfactory, the 24-pole unit, including both the rotor and the stator, were assembled as shown in Fig. 7, where the inside bearing subbase and supports are very clearly shown. Other details of construction, such as rotor fans, the steel ring of the amortisseur winding, stator flanges, the split in the stator frame, and emergency openings are also evident.

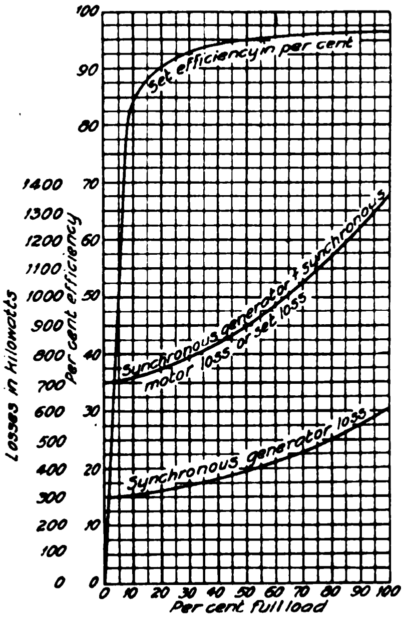

Fig. 9. Performance Curves of 35,000-kw. Frequency Converter

Next, the stator of the 10-pole unit was blocked up from the base, over against the subbase of the inside bearing of the 24-pole unit. The outboard bearing of the 10-pole unit was assembled in place and the 10-pole rotor supported on this bearing at one end and supported at the other end by coupling to the 24-pole unit, as shown in Fig. 8. The stator of the 10-pole machine was then let down to the base level and moved in place, after which its inside subbase supports, subbase, and pedestal bearing were assembled. This method of assembly illustrates one of the reasons for providing space and means for axial shift of the frames to clear the individual rotors.

Testing the Set

Since the set was not assembled in the factory, the tests were made at the installation. These included high-potential and resistance tests on both rotor and stator windings, drying-out run to heat up the coils to eliminate any moisture that had accumulated during transit from the factory and during installation, tests for determination of segregated losses and a heat run with a usual commercial load.

The segregated losses were determined by alternating-current input to the starting motor. This required calculated value of induction starting motor losses to be used. These losses were quite accurately known from previous similar motors, and since the stator loss was small in comparison with the total losses being measured, a variation of a few per cent in the motor stator loss would cause only a very small variation in the segregated losses.

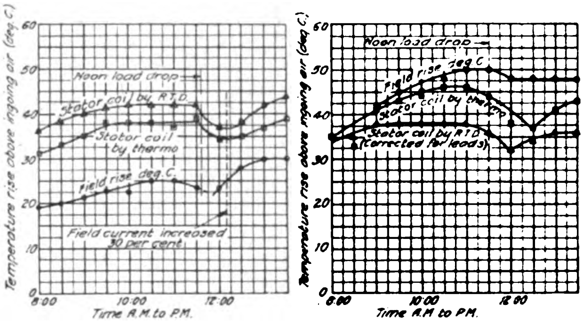

Fig. 10. Curves of Heat-run Data Taken at Installation

The efficiency and loss curves for the normal direction of power flow, *i.e.*, converting power from 13,500 volts 3-phase 60-cycle 0.80 power-factor to 6750 volts 3-phase 25-cycle 0.85 power-factor, are shown in Fig. 9. The efficiency curve for normal reversed power flow, *i.e.*, converting from 6750 volts 3-phase 25-cycle 0.87 power-factor to 13,500 volts 3-phase 60-cycle 0.75 power-factor is practically the same, although the losses of the two units are slightly different.

The heat-run data have been plotted in Fig. 10. It is to be noted that all of the temperatures had become constant before the noon drop in load with the exception of the 25-cycle rotor coils. After noon the 60-cycle field was increased nearer to rated field by taking more reactive kv-a. and the temperature became constant by the time the 25-cycle field had reached a constant temperature.

Acknowledgment

The author wishes to acknowledge the valuable contributions of Mr. Henry H. Kerr, Superintendent of the Electrical Department of the Toledo Edison Company, who furnished the information on the use of the frequency converter, the information on the Toledo Edison System, and the System Load Curve.

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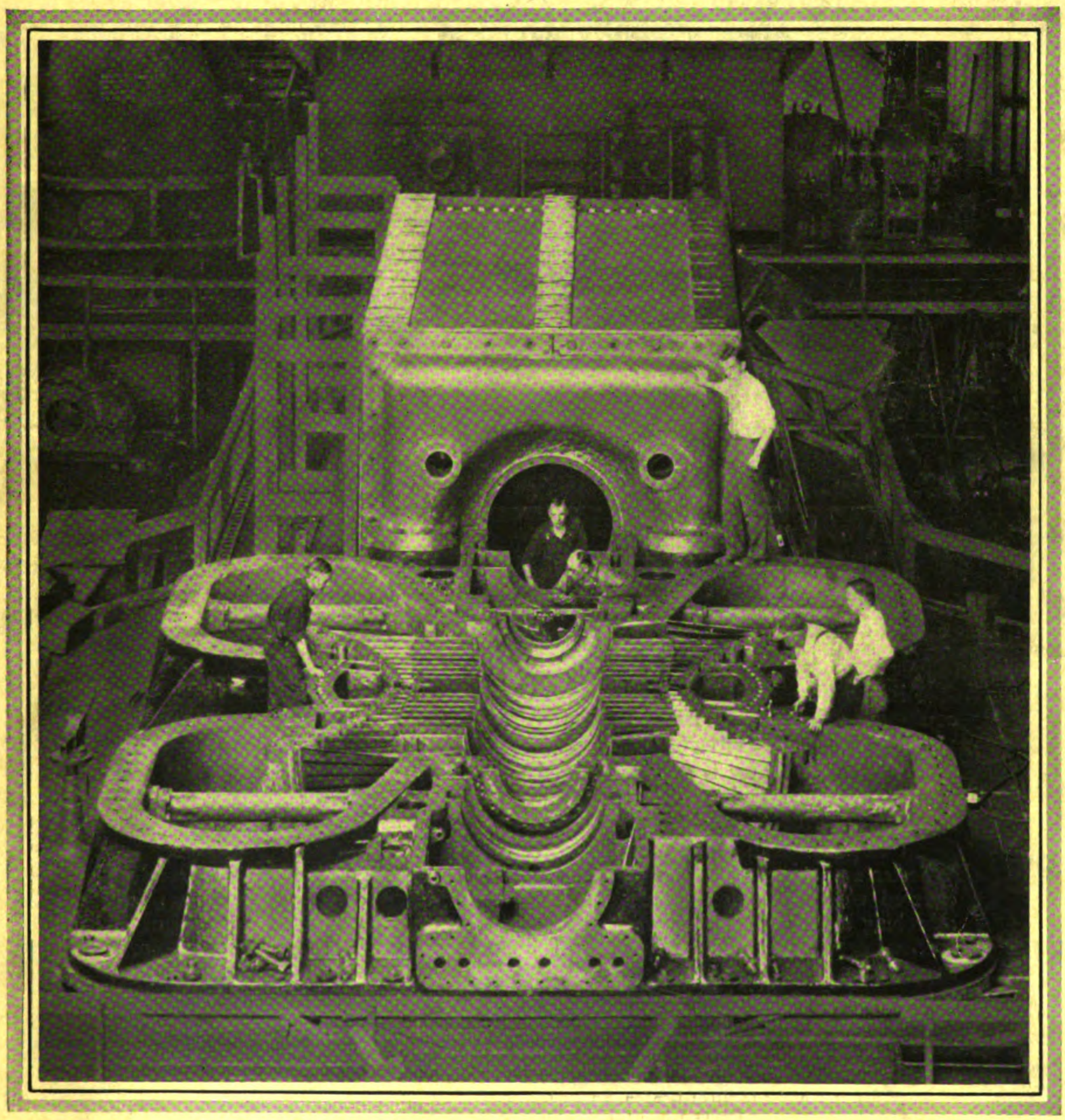
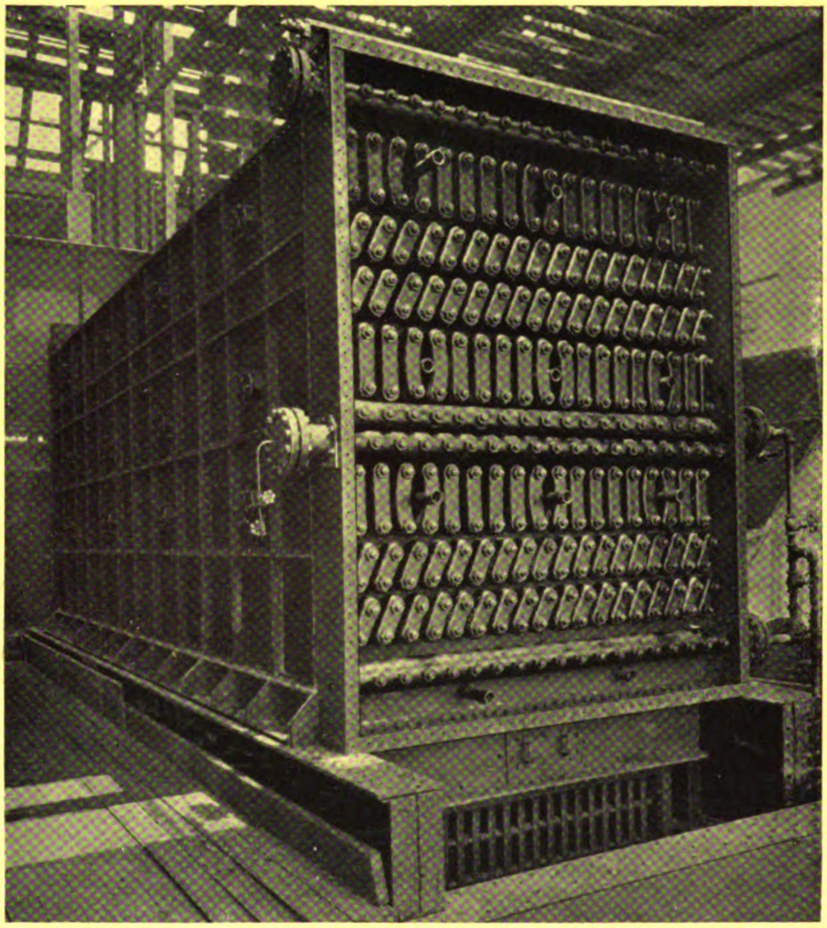


THE LOWER HALF OF THE LOWER HALF

A 110,000-kw. 1200-lb. vertical-compound turbine generator in course of assembly for test. The portion of the unit shown is the lower half of the double-flow low-pressure turbine with its generator. On top of this turbine and generator will be mounted the high-pressure turbine and a duplicate generator

In This Issue: *Selsyn Control Equipment* *Illuminated Ice* *The First Fifty Years*
Crystal Structure *Turbine Development* *Thyratron Control for Spot Welding*
Loud-speaker Efficiency *Harmonics and Power-factor* *New Permanent-magnet Oscillographs*



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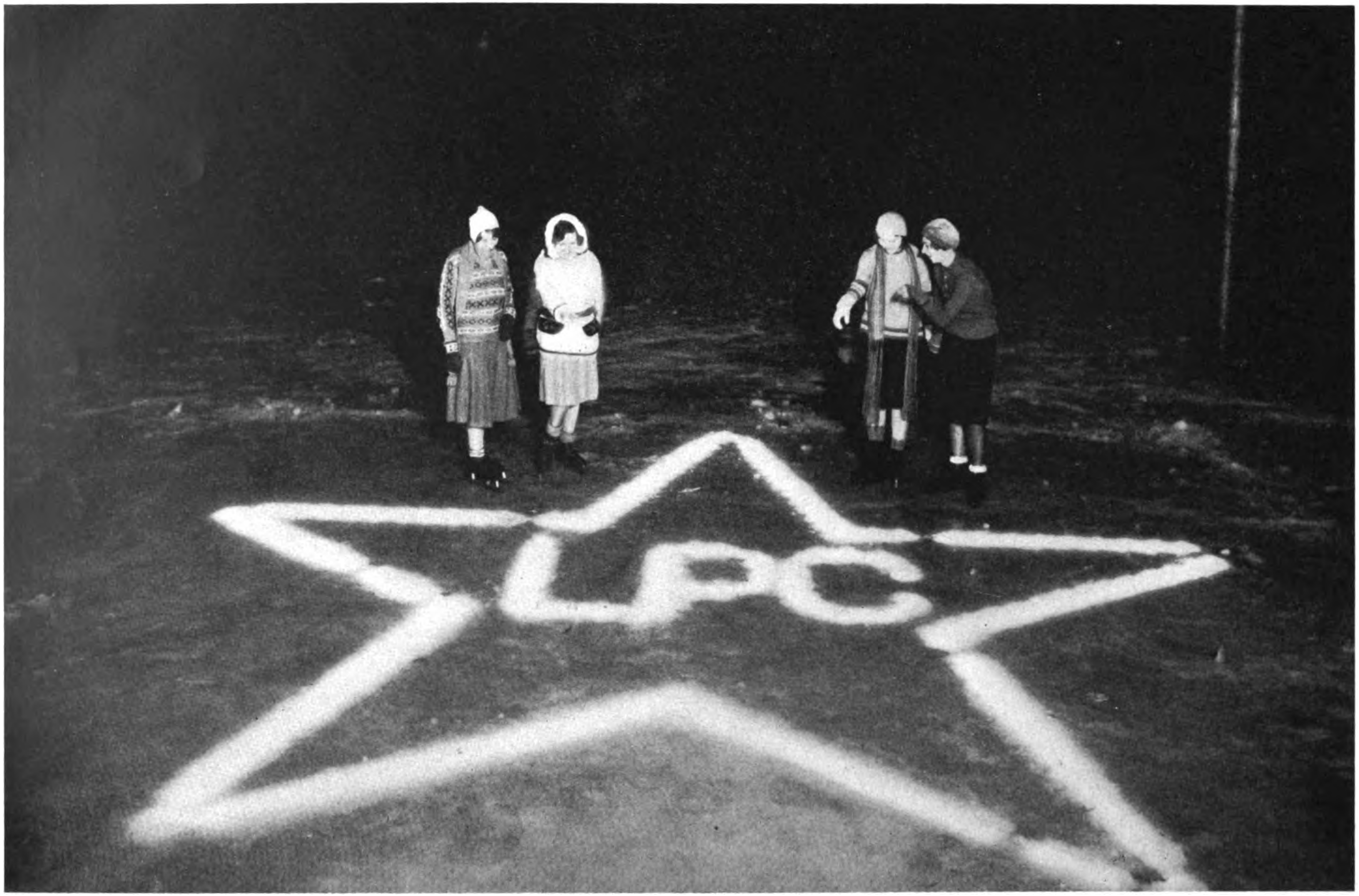


GLOWING ICE

A design formed by electric lamps frozen into the ice of a skating rink at Lake Placid Club (N. Y.).
This new form of decorative lighting holds many possibilities. *(See p. 614)*

GENERAL ELECTRIC REVIEW

Vol. 33 September, 1930 No. 9

WATER

There are many things essential to life and it should help to dispel the gloom of the pessimist to learn that the commonest and most abundant are the most useful and the most used. So marvelous are Nature's materials and her plans; and so complex and wonderful are their actions, interactions, and reactions that whenever we attempt to study and analyze any one of them we are enticed to believe it the most interesting and important of them all.

Each event in Nature is anteceded by some other phenomenon which is its cause, and followed by others which are its effects. And so the great natural game is played continuously with matter and energy, and time and space, as the all-essential entities; and with the present as ever the child of the past, and the parent of the future. It is thus that Nature eternally pursues her uninterrupted and triumphal course —always obedient to the inflexible law.

To an idle mind water may appear as a very simple thing useful for drinking and for ablutions, but so common a thing that to make a study of it would seem more or less of a joke. And yet a little contemplation leads one to recognize it as the greatest of blessings and the most interesting, or one of the most interesting, things on earth. It is the greatest architect and the greatest wrecker in the world, and performs so many highly complex functions that no man or collection of men, ever has told or ever could tell the full life story of a single drop of water or record even a tithe of water's work and water's mission on the earth.

To the engineer, financier, or social economist it may be an interesting fact that of the estimated 454,000,000 potential horsepower in our mighty rivers and majestic waterfalls we have so far harnessed but 33,000,000.

It may further interest these gentlemen to calculate and contemplate what the mighty waters of our oceans and seas, under the conflicting gravitational pulls of the earth and the astronomical bodies, might do for man had we the knowledge to use the tides as they sweep around our earth twice every 24 hours. To compare the energy in the tides—that one cycle per 12 hours—with all that man has developed with his 25 and 60 cycles per minute, is like comparing the energy of the elephant with that of the flea. We hope that the time will come some day when the engineer will not rest content to let the poet and the idle dreamer, in fancy's flight, hitch his chariot to a star, but rather that he in reality will find a way to hitch his turbines to the moon. The horsepower and the dollars and cents would be unthinkably large, but even if this were accomplished it would be one of Nature's smaller services to mankind.

How hopeless it is to try and tell even the opening chapter of water's story. Some genius should tell it in poetry, because it is poetical, rather than leave it to be told in the dull language of facts and figures. But data, cold as they may be, are almost necessary.

Murray tells us in that excellent little book of his entitled "The Ocean" that the earth is the only planet in our solar system that has oceans on its rocky surface. Apparently Mars and the moon had. We wonder if he is right? Probably he is. But life (and we are all so egotistically interested in life) could exist in some form in a moisture-laden atmosphere and on the surface of a planet surrounded by such an atmosphere (if analogy is a truthful teacher), for we know that life is present everywhere throughout the mass of our oceans from the equator to the poles, and from the surface to the abyssal depths. Also life, the organized molecule, or collection of such, is found everywhere on the dry earth, in every zone from the tropics to the poles, on every crag, and in every cranny. Because, and simply because, water is, or has been, there. Whenever Nature's trinity of essentials meet, that is, where earth and air and water meet, we find life and find it most abundantly.

Murray tells us that the estimated volume of water in our oceans amounts to 324 millions of cubic miles and that the volume of our entire terrestial globe is 259,850 millions of cubic miles. Further, that the dry land above the sea level is estimated at 23 millions of cubic miles.

The waters of our little chattering streams, and of our mighty rushing rivers, and the "Break, break, break" of the sea on the shore, are eternally working to tear down the solid land and carry it to the sea. In doing this they erode the earth into those fantastic forms that Scott tells of so beautifully in his "Lady of the Lake":

> "The rocky summits, split and rent,
> Formed turret, dome, or battlement,
> Or seemed fantastically set
> With cupola or minaret."

No one who knows and loves the great Southwest can read these lines without calling to mind some of the most extravagantly beautiful examples of water's work, or rather the work of water, wind, and sand blast combined. Nature's architecture is best seen in the desert countries of the world, because there it is left bare for our eyes to behold. But water, aided by other mighty natural forces, is incessantly working everywhere; all our mighty mountain ranges are being perpetually and relentlessly nibbled down.

> "The hills are shadows, and they flow
> From form to form, and nothing stands;
> They melt like mist, the solid lands,
> Like clouds they shape themselves and go."

But no part of the unnumbered millions upon millions of tons of material carried to the ocean in suspension and solution by our great and little rivers is wasted. The mighty layers of rock being built to-day by these water-borne materials will some day be thrown up into the mountains of to-morrow. Murray once calculated that 5,000,000,000 tons of saline material alone is carried to the oceans annually by the greatest of all transportation systems—our rivers.

Every day of every year 300 cubic miles of water is raised from the oceans and dropped on the earth. That is to say, during every second 16,000,000 tons of rain descends from the clouds to carry on that continuous drama of rearranging everything that has life and things that have not life. Who could ever tell the story of water's manifold works in its passage from the sky, over and through the earth—in and through living organisms, into the rivers and back to the oceans, to be raised again and again, and a million times again. And it is only a tiny fraction of the sun's total energy that falls upon our little earth and performs this unthinkably gigantic task! It makes one sometimes picture the whole world as a great living thing pulsating with continuous activity and perpetual change, those two most conspicuous properties of every living organism.

To the chemist water is just an oxide of hydrogen. Simply H_2O. But we believe there is no definite knowledge of water's molecular arrangement. Its unnumbered properties and its ubiquitous career on Nature's kaleidoscopic stage lead some to believe that it may exist with various molecular arrangements. Probably it exists as H_2O, $(H_2O)_2$ and $(H_2O)_3$. If so, this may account for many of the marvels it performs.

Absolutely pure water is exceedingly hard to prepare. Practically everything is soluble in water. Nearly every gas, liquid, and solid, will dissolve in water. Some are very soluble, while some dissolve in only such small quantities that only by the most searching examination can their presence be detected. It is for these reasons that water is never found in Nature in the pure state.

The majority of chemical actions in the organic and inorganic world takes place in the presence of water, and in that simple statement probably lies the greatest unwritten volume of the history of the world and of the story of evolution.

Could a more wonderful statement be made concerning water than to tell that every living thing on earth, and in water, is composed mostly of water? Some forms of vegetable life we believe are more than 90 per cent water. Man, taking the lowest estimate we can find any authority willing to make, is at least 60 per cent water. The younger the animal the more water he contains and therein lies, at least in part, the story of metabolism.

Not only do all living things consist mostly of water but all aquatic life owes its very being to one of water's most curious properties, namely, that after increasing its density on being cooled down to four deg. C., it expands rapidly on being further cooled. This unique property makes water in the solid state lighter than in the liquid state, and so ice floats on water. Were ice heavier than water it would sink as water froze, and our ponds, lakes, rivers, and oceans would become solid masses of ice and life would be destroyed.

This same water that is lighter in the solid than in the liquid state, will, when converted into steam at 100 deg. C. expand to 1700 times its volume at ordinary pressures, and will absorb 538 calories of heat per gram as the latent heat of vaporization.

Since the days of Newcomb, Watt, and George Stephenson man has been raising the temperature and pressure of steam in his boilers to ever higher figures. And who can estimate what the expansive power of steam in our engines, and the high velocity of its molecules inpinging on our turbine blades, have done for civilization since those days.

The simple fact that water in the liquid state has such a very large capacity for heat, double that of either steam or ice, causes the water not to be warmed by the sun's rays to the same extent as the land. Conversely water cools less quickly in the absence of the sun's rays. This property of water gives us our inshore and offshore winds and largely determines many of our changes in weather. Also this property of water turns our oceans into mighty storehouses of heat and preserves life on the land during winter.

It takes 30 times as much heat to raise a pound of water one degree in temperature as it does to raise a pound of mercury the same amount. But that is another story, yet one that will some day lead to our using monoatomic liquids in our boilers and, incidentally, perpetuate the work and fame of W. L. R. Emmet.

Before the days of that richest and crustiest of all wonderful old chemists, Sir Henry Cavendish, the brains of an awakening age, water was considered an element. Prompted by his innate genius he prepared pure hydrogen and burnt it in air and thus formed water. He was the first to reveal to us the fact that water was a compound—a secret that had lain hidden in Nature's bosom for unrecorded centuries.

H. L. Fairchilds wrote a fantastic monologue on the adventures of a "watermol" in the air, on the earth, and in the sea. But that is the subject for many volumes. However, we feel that it does the engineer no harm sometimes to raise his eyes from his coal pile and boiler to watch the watermols, that may be in his boiler to-morrow, chasing about in the woolly, fleecy, clouds as they assume their many fantastic shapes and melt away. His imagination may be fed by Shelley's beautiful verse:

"I am the daughter of earth and water,
And the nursling of the sky;
I pass through the pores of the ocean and shores,
I change but I cannot die."

We think it is too drastic a statement to make, as some have, that all the waters of the earth were fashioned in volcanoes. Apparently we are not vouchsafed a knowledge of the birth of the elements or compounds on our earth. Was there as much water on the earth a million years ago as there is now? Will there be more or less a million, and a million million years hence? If the moon had an atmosphere once how did it lose it? Had we once helium in our atmosphere that has escaped? "What we know is but little, what we do not know is immense."

When a watermol—that invisible but ubiquitous speck, so small that it takes at least a crowd of two thousand of them to be visible to the most powerful microscope—has its motion stimulated by a sunbeam and evaporates from the ocean's surface, it is a free entity in the air. It may be carried anywhere, it may become a part of any living thing on earth, it may become a part of a million times a million inorganic substances. It may enter partnership with a cloud, it may marry a snowflake. It might have been in Julius Caesar's eye during one yesterday of its existence and it may be in the petal of a rose in one of its to-morrows.

"I sometimes think that never blows so red
The Rose as where some buried Caesar bled:
That every Hyacinth the Garden wears
Dropt in its Lap from some once lovely Head."

Watermols have been doing all these useful and interesting things for millions upon millions of years. The sea is full of people. All living things, after that curious change takes place that man calls death, become in one way or another dehydrated. All the kings of the earth, the princes, the clowns, the archbishops, the children of the slums, and the millionaires are there in part. A great democracy, the sea! Even the useless ones in the world's history become useful when they surrender to Nature the things that are Nature's.

Perhaps some watermols on reaching the outermost portions of our atmosphere where they find fewer and ever fewer molecules of nitrogen, hydrogen, and oxygen to collide with, may in their greater freedom take too long a stride and slip beyond the power of the earth to hold them its prisoners. If so, and we think it is possible, they find another master. They are, and ever must be, subject to those laws of Nature propounded by Newton. They, if free from the earth, would become tiny planets and pursue their perpetual journey around the sun obedient to the planetary laws. Unless by chance they fell into the influence of the gravity of some planeloid or of some minor or major planet. So it is not at all impossible that a small part of some once stately and dignified archbishop on our earth is now, with the utmost modesty, floating about in a Martian cloud.

They say that fish are oblivious to water until they leave it. So are most men and women oblivious to the comedy that Nature plays until they just sometimes leave off taking themselves too seriously. Watermols have eternal life; they leave it to man to fuss about immortality.

But we may be criticized if we are too frivolous or too philosophical in a technical magazine—and the dividing line is so narrow! So we must conclude. But we can't help saying that next time we see a "dour Scots engineer" with his hand on the injector, to force, he knows not what, into his boiler to raise steam; but perhaps a little bit of Cleopatra and Mark Anthony, a little of Romeo and Juliet, and some of so many of the children of love and tragedy, of poverty and wealth; we will murmur—

"Gently, Brother, gently, pray!"

J. R. H.

The First Fifty Years

Address at a Testimonial Dinner Given by Officials of the General Electric Company to Professor Elihu Thomson and Edwin Wilbur Rice

By OWEN D. YOUNG
Chairman of the Board

We feel that so eloquent a tribute to our best loved and most able pioneers should be recorded in our pages. So, we print Mr. O. D. Young's recent eulogy to Mr. E. W. Rice and Professor Elihu Thomson in full.—EDITOR

IN June, 1880, a boy, then 18 years old, a pupil of the Boys' Central High School of Philadelphia, who had had the incomparable privilege of associating with an inspiring professor, contributed to his graduation exercises an essay on the utilization of electricity. It is short, and with your permission, I will read it as an introduction. It takes momentum to start a speech —it requires either character or inertia to end one. Frequently, the latter is resorted to, and often it works slowly. This is the essay:

Mr. Rice's Essay

"It is natural for persons to regard that age, that nation, and that climate in which they live as the best. Partaking of the same feeling, we consider this age remarkable, especially in its scientific aspect.

"During this age of discovery, invention and progress, two periods are especially memorable for the utilization of two mighty forces.

"The first period opened with the discovery of the power and the use of heat. It is heat which gives motion to the steam engine; which impels the ocean steamer, and which runs our mills and factories. Heat sets free the imprisoned gas, which dispels the darkness of night; heat glows in the fire which administers to our comfort; but when uncontrolled it destroys with irresistible fury the strongest and proudest of man's works.

"We now, however, stand upon the threshold of a new era. Another force is to carry forward the work begun by heat; and all the wonders which that force has accomplished are to be eclipsed in the triumphal march of that subtle, mysterious and powerful force, electricity.

"Many centuries elapsed after the beginning of the Christian era, before the human mind was prepared to appreciate this grandest of the physical forces.

"The pealing thunder and the vivid lightning were incapable of arousing the world from its lethargy. It required the silent voice of the telegraph, which sends the thoughts of man flashing between cities, states and nations; spanning the broad ocean and uniting continents with its vital power. This gave a new aspect to trade, a new impetus to commerce, a new luxury to mankind, and it has virtually become the nervous system of the world.

The Telegraph System

"As the nerves, starting from their great centers, spread over the body into innumerable branches, receiving and transmitting with a rapidity of thought the intelligence of an injury inflicted, or impression received, so is the world being gradually provided with its vast network of nerves, the telegraphic system. Not an event of importance can transpire in any portion of this great world, the knowledge of which is not instantly conveyed, through these iron nerves, to the great centers of civilization.

"This transmission of thought constitutes a triumph which was formerly astonishing, but now the handwriting, drawings and even the human voice itself are transmitted to great distances.

"The telephone by which this last wonder is accomplished is an instrument whose value and utility are too well known to require explanation. Its beautiful simplicity, its marvellous delicacy and surpassing perfection cannot fail to excite our wonder and admiration, while the telegraph seems by comparison like the scope of the unassisted eye compared with the sublime infinity of time and space revealed by the aid of the telescope.

"But the requirements of mankind are ever increasing, and we will not always be satisfied with speaking to a distant friend but shall wish also to see him; and no doubt this will be possible in the near future. There has been, indeed, already discovered the germ of a new instrument for its accomplishment.

Electric Lighting

"Electricity, however, is to do even more than this; it is to come yet closer home. In the evening gas affords us an illumination which a few years ago was deemed marvellous; but in the onward stride of civilization, the yellow, flickering gas light will soon become a thing of the past, and electricity will diffuse its steady, white and beautiful light, turning the darkness of night into the splendor of noonday. Thus shall it literally come to pass that 'At evening time it shall be light.'

"Moreover, that same force which in the evening furnishes our light will during the day be converted into motion. For no visible, tangible agent can work with so much force and precision as electricity. It annihilates that greatest obstacle, distance, and performs work of every description from the driving of the heaviest machinery to the regulation of the most delicate timepiece.

"But all these wonderful applications are but forerunners of the dazzling future. When our homes are made bright by electricity and our mothers' weary hours over the sewing machine have ended, when our streets at midnight are as bright as at noonday and our deep and darksome mines are resplendent with the electric light; when we can see and converse with our distant friends, though separated by thousands of miles; when city speaks to city and nation to nation, then shall all parts of the world be so linked together that a reign of peace, prosperity and comfort shall be inaugurated which, Heaven permitting, shall endure until temporal things shall have an end and man shall be with his Creator."

Evidence of Partnership

That was the graduation essay of Edwin Wilbur Rice. Professor Elihu Thomson was his teacher. If one does not carry the comparison too far, he might exclaim with Isaac—"The voice is the voice of Jacob, but the hand is the hand of Esau." Anyhow, I submit it as the first documentary evidence of the intellectual partnership between these two men, which has been maintained so long and fruitfully. Those of you who are quick in subtraction, or have your slide rules handy, will say fifty years, but I say one-third of the life of the United States. Perhaps the most imposing one-third. The slide rule, properly manipulated, will, I suppose, always tell the truth, but it requires something more to get the whole truth. It is not fifty years of which we speak, but one-third of our national life. If projecting ourselves forward a few hundred years, we look backward with the compression which perspective inevitably compels, it is easy to see that to the student, then, there will appear only a small interval in time between Benjamin Franklin drawing electricity from the clouds and Professor Thomson and Edwin J. Huston testing dynamo-electric machines for the Franklin Institute. We are in the habit of thinking that the United States is very old and that the electrical industry is very young, but superimposed on each other in the narrowing perspective of time, they will tend more and more to become identical.

Let us take a look at these fifty-year periods. On July 27, 1780, one hundred and fifty years ago tonight, we were engaged in the momentous struggle to acquire for ourselves political freedom. A declaration of intention had been made on July 4, 1776, and ever since that time, we have maintained the struggle, with varying success, to make that declaration effective. The economic freedom of the individual was then perhaps at its maximum. It was a new country with ample natural resources and small population. Every white man had or could have his cow, his pig, his sheep, and his garden. His clothes, food, light and power were home made. The difficulty was not economic freedom for the individual; it was rather that such liberty produced the bare necessities of life, and those only with the greatest effort. During these one hundred and fifty years, we have sacrificed something of our individual liberty in order that we may have more and better things with less effort and less exhaustion.

A Costly Lesson

On July 27, 1830, one hundred years ago, we had developed our machinery of government to provide our political freedom, and we had not yet sacrificed, to any great extent, our economic freedom. Neither had we increased much the material goods essential to comfort over those which had existed fifty years before. A new problem of political freedom was thus forcing itself on our horizon. The question was becoming acute. Did our declaration of fifty years before mean or ought it to mean white men only are to be free? There were black men who were not. Strenuous endeavors were then made for a compromise. They failed, because you can no more compromise on such an issue than you can compromise on the reading of the slide rule. It was costly for America to relearn that age-old lesson.

On July 27, 1880, we had learned and paid the price. The right of all men to political freedom had been established, but the economic freedom of men was diminishing. Manufacturing had been gradually transferred during the preceding fifty years from our kitchens to organized establishments. Steam and falling water had been harnessed for power. Transportation by railway had driven the individual teams and drivers from the roads. An era of industrial expansion was at hand—an era of organized national transportation was here. Even the telegraph and the mail were organized for communication. Large numbers of men for the first time were becoming either employers or employees.

The Balance Sheet

In that very year in New Britain, Conn., in one wing of a little factory, Elihu Thomson and Wilbur Rice, aged 27 and 18 respectively, were industriously engaged in harnessing for use a new form of energy which in the fifty years since has played such an enormous part in the promotion of our material well-being. What truly marvelous contributions they have made to their own country and to the world, and yet, every balance sheet, whether it be of the individual or of the corporation, or of society as a whole, has its two sides. When one writes something on the asset side, it is inevitable that an entry should be made on the liability side. In praising men's accomplishments, it is usual to speak of the asset side alone. This merely results in that kind of unlimited praise which is unsatisfying to the men themselves and unconvincing to others. A fair appraisal of a man's effort is not what he has written on the asset side of the balance sheet of life, but how much of the counterbalancing entry on the liability side is surplus. That measures the real contribution of men, and we can without reservation, even in their presence, appraise the contributions of Professor Thomson and Mr. Rice, both to the General Electric Company which they have so long and faithfully served, and to society as a whole, by the surplus on the liability side of the balance sheet.

The contribution which electricity has made to the asset side of the nation's balance sheet certainly need not be mentioned in detail to this audience by one who is least competent of any in this room to do so. Electricity has made energy portable, divisible, and sensitively controllable. Anyone who has ever held a plow in a rocky field, behind a three-horse team, will appreciate the value of the sensitive and quick control of energy. I can testify from experience, not yet and never to be forgotten, how a horse-fly can make your ribs sore with a plow handle when the reins are slack. Therefore, I salute with personal feeling the divisibility and controllability of energy which your electrical equipment has provided for the race. It may not yet have been applied to the plow, but I commend that to your future attention.

Must Not Displace Men

Anyone can see without detailed recital what it means to have power available anywhere, in large or small quantities, under perfect control. Large power might be provided by other means than electricity, but it was difficult to transport and control. Small power was largely furnished by human beings. It was portable only as the human body was transported. It was divisible and controllable only after the long training of the human muscles. That was skill, and so we must think of electricity, not only as relieving human exhaustion, but as taking the place of human skill. Insofar as it relieves men from drudgery, that is on the asset side of the balance sheet. When it throws men out of work entirely, that, temporarily at least, is on the liability side of the balance sheet. When it displaces men of skill and experience, and substitutes for them untrained youth, that, too, may be a liability to society, notwithstanding that it produces more and cheaper goods than the old method. New inventions must put displaced men at work, and new fields for skill must be developed. Society cannot lose the skilled man or the disciplined man.

Yes, electricity contributes, affirmatively, to the comforts of men, and, negatively, to their relief from physical exertion. It provides more things to enjoy, and more leisure for their use. Here a new problem arises. How shall we use our comforts and our leisure? The church and the school must teach us how to use them properly or the counterbalancing item on our balance sheet will not be surplus, but the notes payable of a weakened race.

Task of the Schools

So my dear Professor Thomson and my dear Mr. Rice, the Boys' Central High School of Philadelphia, through you, has contributed much to the asset side of a nation's balance sheet. It remains for that high school, however, and all others, and colleges everywhere, to teach boys to develop equally ingenious and inspiring methods for the use of the spare time which you have given them. It is as dangerous to fool around with leisure as it is with your large transformers. Leisure, like them, seem quite harmless, but like them, when misused, it has power to destroy. You, in the physical sciences, are liberating human beings, but religion and the social sciences must teach them the discipline of self-restraint. So much for the nation's balance sheet discussed in terms of surplus.

What about the General Electric balance sheet? Now what have you gentlemen, Professor Thomson and Mr. Rice, contributed to that? Let us take a look at the asset side and see what there is on it which you have made. We have plants which cost $209,000,000. You have never built any buildings. Architects and construction men did that. So far as I know, in these 600 acres of floor space not a single foot has been laid by you. Yet, to many, these great plants are the conspicuous monument of our success. If we were to take an inventory of our physical equipment of tools, I doubt if there is much to which you can claim parentage. Some remote, and to the general observer, unrecognizable off-spring may still survive from the efforts of your earlier days. I doubt, however, whether you yourselves can point tonight to a single physical thing in this mammoth array of buildings and tools which you have made.

No Material Contributions

Our quick assets of cash, receivables inventories, amounting to $255,000,000, in 1929, are not as such contributions by you. Perhaps you were fortunate enough, and probably Mr. Rice is under suspicion, in having contributed a few hundred dollars to the original enterprise, and having held this interest ever since with the great multiplication which the years have made. Outside of that, not a dollar in the banks, not a single piece of raw or finished material has been contributed by you. I am sure there are none of your obligations in our notes receivable. Finally, we have the item of patents, to which I think you both may have contributed something, but even so, you see we regard them as quite unimportant, because they are on the balance sheet at $1. What a discouraging exhibition it must be for men to have given fifty years of faithful and conscientious service to a concern like the General Electric Company and not be able to find an identifiable, physical thing on the asset side of its balance sheet as a monument to their service. And yet, men of the General Electric Company, there is not an item on that balance sheet which could have existed at all, or if it did exist, would have been worth putting on the asset side of any balance sheet, had it not been for the work of Professor Thomson and Edwin Wilbur Rice. There is not an identifiable separate thing that stands on that balance sheet as their monument—it is the balance sheet itself. I do not mean by that others have not contributed much. Certainly, one could not speak of the General Electric balance sheet with satisfaction to himself, or to Professor Thomson or Mr. Rice, without recalling that great genius who transmuted the abilities and affections of men into effective and productive service. Charles A. Coffin did that. It is no reflection on our guests here to say that the balance sheet could not have existed without him, and it is no impairment of his contribution to say that the balance sheet could not have existed without them. In large measure, what all three of these men contributed to the General Electric Company was a vision of the future each in his separate field; a courage to undertake and a determination to perform those things which each could do best; and most important of all, a spirit, not so much of tolerance as active coöperation in pulling the enterprise through together with respect, yes, with affection for each other. That is what made the balance sheet of the General Electric Company—that is what made its spirit. It is that great intangible thing which you can not touch with human hands, or see with human eyes, that thing which cannot be written on a balance sheet, which has made the General Electric Company the greatest electrical organization on earth, and which will maintain it so as long as that spirit and effort still survive. The balance sheet says our assets are $500,000,000. The market says our shares are worth $2,000,000,000. If you wish to subtract the first from the last figure, you will get a valuation of the intangibles, a substantial part of which was contributed by our guests.

Fifty Years of Service

So we celebrate today the fiftieth anniversary of service of those two productive and distinguished men. It is the service and not the fifty years on which I wish to lay emphasis tonight. We usually measure youth and age in terms of years, and by and large, perhaps we have to use that yard stick. Obviously, however, it is not infallible. Not all minds crystallize into rigid moulds with the mere passing of years. Not all arteries harden. Some resist with astonishing success. Perhaps it depends somewhat upon how their minds are engaged. A mind which is dealing with tangible things naturally is impressed with physical stability. Managers of plants, to a certain extent, must resist change, certainly too constant change. Efficiency requires that such men be enemies of constant innovation in order that they may be friends of economical production. On the other hand, a mind which is dealing with intangibles is apt to find not only its stimulation, but its nourishment in the constant seeking and apprehending of the new. A new system may be built on a single hypothesis, and over night a new discovery may destroy its very foundations. Minds engaged in such undertakings must be prepared to scrap everything they have at any minute and begin all over again. The thinking of years must be as freely discarded as a worn-out suit of clothes. Men dealing with intangibles, who are capable of doing this, are young, despite their years. Conversely, men who are incapable of doing it, may be old at youth. The man who lives with ideas as distinguished from things has a life which is an exciting serial in which he is always anticipating the new installment. His value is not impaired by age so long as he retains these qualities. He is old only in wisdom and experience.

Minds Still Resilient

Professor Thomson has dealt largely with these intangible things from the beginning, and he, as all will testify on the criterion which I have mentioned, is young. We congratulate him on his youth. It is that we celebrate tonight. Mr. Rice for many years exposed himself to the danger of dealing with physical things, and yet his mind too has kept its resiliency and its mutability. It is a striking thing in Mr. Rice's career that, in whatever field he has worked, he was to his associates strongest there. If I were to ask tonight the men associated with him in the handling of these great physical plants and their tools and machinery, I would receive the unqualified assertion that while he was a good scientist, yet as a plant manager he was an incomparable genius. They would say, therefore, that he was first in management, and second in science. If I were to go among the men in our research laboratories, possibly even to Professor Thomson himself, there would be a note of regret that such a great scientific man should have been withdrawn from that field to the mere handling of physical things. They would say undoubtedly that while he was a good manager, he was a greater scientist. I propose to discard the testimony of all, and to make up my own mind about it. So I assert here that a mind which has been exposed for so many years to the rigidity of physical things and still has not absorbed any rigidity itself, carries its own overwhelming testimony that it is scientific by nature and managerial by training.

It was a great thing for the General Electric Company that a scientist had or developed the capacity of management. There were days when we had to sacrifice scientists for managers. Fortunately that is true no longer, and we look forward still, Mr. Rice, notwithstanding your retirement from active service, to an expectancy of years and to a productivity of mind outside any organized obligations which will demonstrate beyond contradiction that my assessment of your predominating scientific capacity is correct.

Company Still Youthful

The General Electric Company has been passing through the period of youth and its natural concomitant rapid growth. It has not yet reached the period where Vitamin "B" needs to be artificially supplied. Neither yeast cakes nor tomato juice cocktails are yet necessary. That is an important matter when speaking of an organization, because an organization, like the individual, has within it the capacity of growth. It may live or die; it may grow or decay, and there is no period in its life when it is not doing one or the other. We are the trustees in our generation of that organized institution, and we have the responsibility which goes with that high privilege of trusteeship. We, for the most part, are second generation people, who have inherited from those who have gone before and whose obligation is to hand on to those who come after. We have a worthy ambition to pass on more than we have received, not merely in plants and capital, not merely in acquired experience or scientific achievement, but more in the sense of a continued, healthful, well-functioning body, still endowed with the spirit and daring of youth, but inevitably restrained by the accumulating experience of the years. We need both the enthusiasm of youth and the experience of age. To get the right blend is difficult. Nature's way is to sacrifice ruthlessly age to youth. She is wasteful of experience, and so each generation in the natural world makes over and over again the mistakes of its ancestors. Only a small modicum of improvement is conserved through the generations. An organization like ours, however, has a natural tendency to do the reverse thing. Inexperience is so costly, youth is so reckless, that one shudders at the waste involved in the education of a new generation. No one knows better what it costs than those of us who have made the mistakes. The problem of the General Electric Company, with its larger and more complicated organizations having constantly greater geographical reach and wider intellectual explorations, is to retain the enthusiasm of youth without sacrificing too largely the experience of age. This we must learn to do. Youth, ever advancing, bold, courageous, energetic, must be given the liberty to develop, and to carry the flag. This does not mean displacement of older men. There is a place for them too, where experience and judgment and wise advice will hold us to a successful course.

So I salute our guests of honor on their service. True it is fifty years and they are yet young. I congratulate the General Electric Company on what they have done and will do. Fifty years from tonight, one hundred years from tonight, if our trust is well performed and our successors worthy, the spirit as well as the names of Professor Elihu Thomson and Edwin Wilbur Rice will stand for creative thought, for bold adventure, for persistent endeavor, for effective accomplishment, and last and best of all, for that generosity of spirit which, by yielding all credit to others, unintentionally conserved it all for themselves.

New Permanent-magnet Oscillographs

General-purpose Six-element Type—Portable Two-element Type—Continuous-viewing Type—Convenience of Operation, Safety, Accuracy, Compactness, and Light Weight Are Notable Features of All the Models

By M. A. RUSHER
Oscillograph Division, General Engineering Laboratory
General Electric Company

THE constantly increasing use of oscillographs by electrical engineers engaged in the design and application of electrical machinery is now extending to the larger group of electrical engineers who use and operate this machinery, to mechanical engineers in their study of vibrations, pressures, and performance sequences, and to development engineers for "visualizing" the new and unknown in their many projected schemes. The medical profession uses oscillographs in the study of heart beats. In schools and colleges, oscillographs make clear to the students things which would otherwise be uncertain and intangible. This extensive use has resulted from a more general realization of the utility of these instruments and from the great advances in design which have made possible their widespread use.

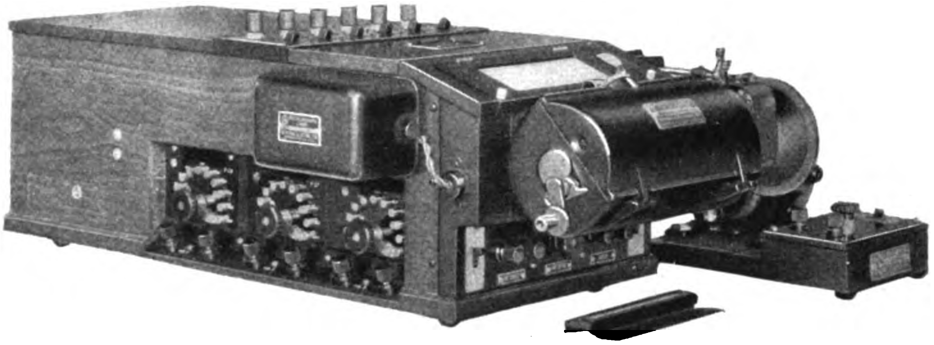


Fig. 1. Six-element General-purpose Oscillograph with Magazine Film Holder in Place, Showing Lamp and Three of the Six Interchangeable Rheostats for Vibrator Circuits

This widespread use is not satisfied by a single design of instrument. For the lower frequencies, such as those up to 2000 cycles per second, the magnetic type of oscillograph galvanometer is used. For higher frequencies the cathode-ray beam, having no inertia, is used to trace the record on the photographic film.

The new instruments using the permanent-magnet type of galvanometer are the six-element general-purpose oscillograph, the two-element portable oscillograph, and the continuous viewing oscillograph.

SIX-ELEMENT GENERAL-PURPOSE OSCILLOGRAPH

The general-purpose oscillograph shown in Fig. 1 has six permanent-magnet galvanometers mounted in an attractive walnut case approximately 25½ in. by 12 in. by 9¼ in. high. A seventh or timing vibrator makes the oscillograph a seven-element instrument for many purposes.

Galvanometers

The galvanometers for potential or current measurement are self-contained and oil-tight, the permanent magnet itself forming the cell box. Each galvanometer is supported in the oscillograph case in a mounting, as in Fig. 2, with adjusting screws for vertical and horizontal adjustment of the reflected beam of light. The galvanometer is clamped in the mounting with a single thumbscrew so that it may be removed easily for repairs or for cleaning. The sensitivity and natural frequency of these galvanometers are equal to that of the corresponding types of vibrators in the electromagnetic oscillograph. A damping liquid has been selected which gives critical damping at normal operating temperatures and is therefore suitable for use when recording transients as well as steady changes.

Three-element and single-element watt galvanometers can also be used, either of which may be placed in the space allotted to one of the current or potential galvanometers. The three-element watt galvanometer is shown in Fig. 3. It is intended primarily for recording the summation of the instantaneous values of power on either grounded or ungrounded polyphase systems. Suitable rheostats simplify the connecting of this galvanometer to the required instrument transformers and the connecting of portable wattmeters to the same circuits for the purpose of calibration. The single-element watt galvanometer is designed to record instantaneous values of single-phase power.

Galvanometer Rheostats

Three rheostats for potential measurements up to 250 volts and three for current measurements are connected in the vibrator circuits of the galvanometers and are conveniently located in the sides of the oscillograph case. Three of these are shown in Figs. 1 and 4. In order that any galvanometer may be used for either current or potential, the rheostats are made interchangeable. Any one may be removed from the oscillograph case by taking out two screws which hold the top of its panel. These screws not only hold the rheostat in place, but clamp together the conductors which form the vibrator circuit. A potential rheostat may also be used in the potential circuit of a single-element watt galvanometer.

No resistance is included inside the oscillograph for the potential circuits of the three-element watt galvanometers. However, openings in the rear of the case enable special cables to be run from a three-element watt galvanometer to an external rheostat. This rheostat has receptacles in its panel for the connection plugs of a calibrating wattmeter. Removing these plugs disconnects the watt galvanometer from the circuit and automatically short-circuits the current-transformer secondaries.

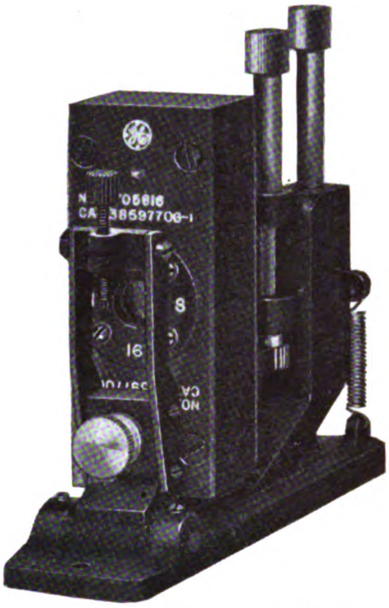


Fig. 2. Permanent-magnet Galvanometer, Clamped in Mounting, with Zero Mirror Attached

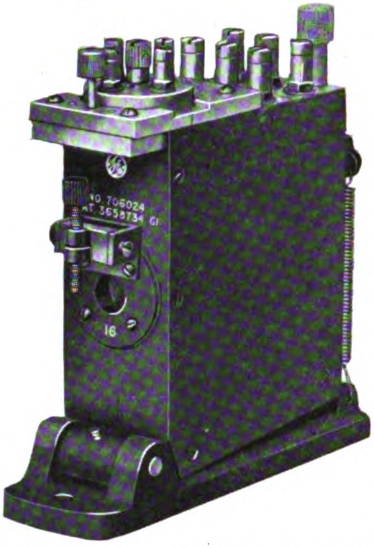


Fig. 3. Three-element Watt Galvanometer for Recording Power on Grounded or Ungrounded Polyphase Systems

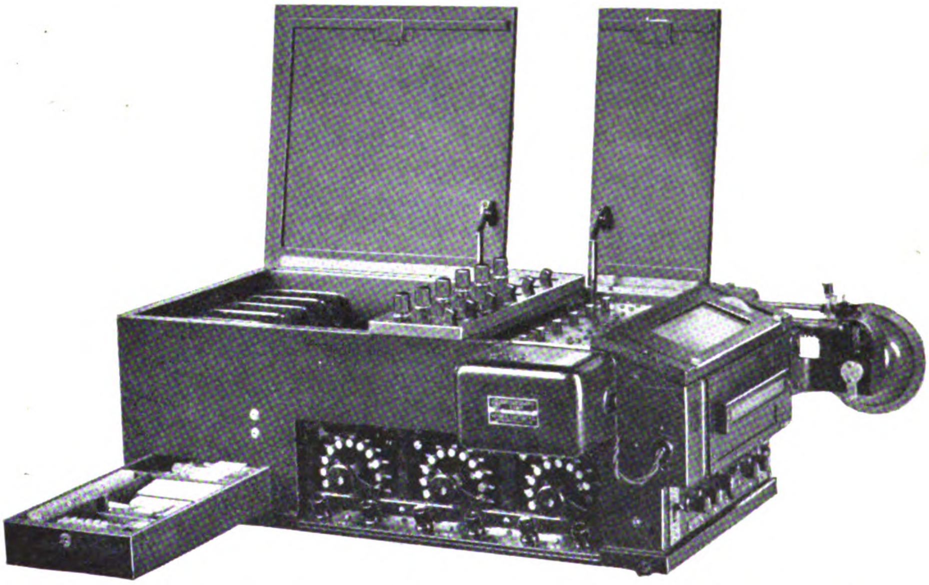


Fig. 4. Side View of the Six-element General-purpose Oscillograph with Covers Open Over Prism Housing and Galvanometer Compartment; also Showing Drawer for Accessories

The oscillograph is not restricted to use below 250 volts since it is insulated to withstand a high-potential test between galvanometers of 10,000 volts at 60 cycles for one minute. It may be safely used with 3000 volts between galvanometers if the connections are brought direct to the galvanometers through the holes in the rear of the case, using external rheostats, switches, and fuses of suitable design. Rheostats are available for use in circuits up to 1500 volts and two of these may be connected in series in a 3000-volt circuit.

Safety and Convenience

The whole oscillograph has been designed for safety of operation together with convenience and simplicity. The connections to the galvanometer circuits are made to convenient binding posts, Fig. 1 and Fig. 4, located along the sides just under the removable vibrator rheostats. The vibrator switches are mounted inside the case with their insulated handles projecting through the top panel in a very accessible location. When these switches are open, the galvanometers, rheostats, and all accessible parts are dead. The fuses are located just back of the vibrator switches and are covered with insulating caps. These fuses have never failed to protect the vibrators in cases where excessive current was passed through the vibrator circuits. Safety of operation is still further assured by insulating the front plate and all operating circuits from the galvanometers, with their rheostats, switches, and fuses, to withstand a high-potential test of 10,000 volts at 60 cycles for one minute.

Switches and connection posts for the lamp and motor circuits, and a rheostat whose setting determines the intensity of the light during an exposure, are all mounted on the front of the oscillograph, Fig. 5. A viewing screen is located just back of the film holder, Fig. 1, so that the intensity of light spots, the magnitude of deflections and the relative arrangement of curves can be seen at any time. A rotating mirror, made from a square rod of fused quartz with platinized surfaces, is located under this viewing screen. This is operated by hand to show the wave shapes and to provide a convenient means for determining whether the connections to a galvanometer need to be reversed to bring the waves into the correct phase relation before making a test.

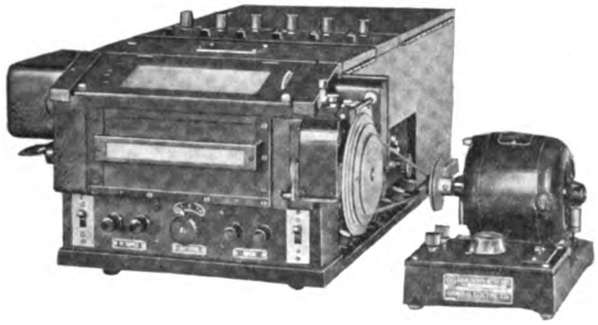


Fig. 5. Front View of General-purpose Oscillograph Showing Viewing Screen, Ground-glass Scale for Calibration, Controls for Motor and Lamp and Motor Unit for Operation from Six Volts Direct Current

Accuracy and Clearness of Records

Accuracy and clearness of records have been given first consideration in designing this oscillograph. Chromatic aberration has been minimized and sharper light spots produced by spacing the reflecting prisms just as far apart as the corresponding vibrator mirrors. This allows the beams of light to enter and leave the prisms normal to their faces. In a large measure this is responsible for the remarkable contrast and sharpness of lines on the oscillograms made by this instrument. (See Figs. 10, 11, and 12.)

Another factor which has contributed to the quality of these records is the concentrated ribbon-filament lamp. This requires only six amperes for normal operation and seven for high-speed records. The light is taken from the inside of a V-shaped filament which is the hottest point on such a filament. The lamp has a remarkably long life because over-voltage is not applied to a cold filament, but to one which is already at normal operating temperature.

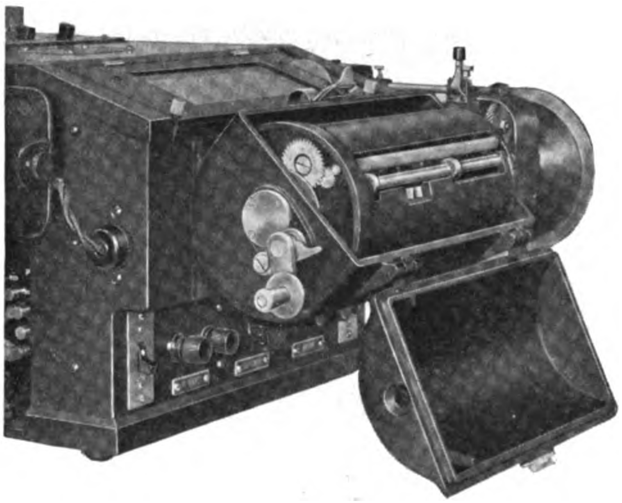


Fig. 6. Magazine Film Holder for Making Three or Five Short Exposures on a Roll Film

The stability and permanency of adjustment of this oscillograph are indicated by the fact that an instrument of this type was recently used in three different tests which necessitated shipping it a total of 800 miles, without any need for adjusting the lamp, galvanometers, or optical system at any time. This was possible because the galvanometers are self-contained and the prisms and lamp, while adjustable, are clamped in position after being adjusted so that they will stand considerable jarring without having their position changed.

Film Holders

The magazine film holder, Fig. 6, as well as the continuous-drive film holder, Fig. 7, which is employed for making long records, may be loaded and unloaded in daylight. Both are adapted to use either films approximately 6 in. or 3⅝ in. wide as desired. The films are run through both holders in such a way that vibrator No. 1 traces the wave at the top of the finished oscillogram and No. 6 the wave at the bottom with the sequence of events progressing from left to right. This greatly simplifies reading the records obtained and prevents errors in interpreting the results.

The records made in the magazine film holder are approximately 11 in. long so that very little needs to be trimmed off the ends for filing with ordinary business correspondence. Films may be obtained for making three or five such exposures. The film is wound by hand from one exposure position to the next the same as in the usual camera.

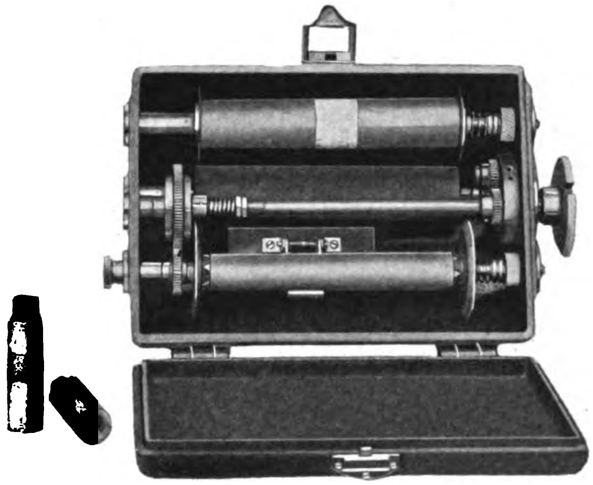


Fig. 7. Continuous-drive Film Holder for Making Continuous Records Up to 20 ft. Long. At the left are adapters to accommodate the use of narrower film

The continuous-drive film holder is also very simple. The whole mechanism is exposed to view by opening the hinged cover, Fig. 7. Records may be made with this holder up to 20 ft. in length. A record of this length may be exposed in 5 sec. or in as many minutes.

Zero Indicators

When using the continuous-drive film holder, it is not possible to make a second exposure on the film with the vibrator circuits open for the purpose of recording zero lines. Adjustable zero mirrors which remain stationary during the exposure of the film may be attached to any galvanometer mounting as in Fig. 2, for recording the zero lines. These are particularly adapted for use when recording direct current. A still simpler zero indicator is provided for use when recording alternating-current waves, leaving a gap each time the wave crosses its zero position. This also serves as a means for identifying waves when they lap over each other, making it easier to distinguish one from another. The use of both of these is illustrated in the oscillograms shown in Fig. 12.

Shutter and Transient-control Switch

The shutter is mechanically operated and is so arranged that the exposure always starts at the beginning of the film. It may be set to start the exposure almost as soon as tripped or with a time delay of several revolutions of the driving pulley. It is very easy to open the shutter by hand for making calibrations on the ground-glass scale or for using the continuous-drive film holder. Resetting the shutter-control mechanism is also very simple.

A transient-control mechanism is provided in connection with the shutter control, which may be used to start a transient while the shutter is open or at certain predetermined times before the shutter operates. This makes it possible to accomplish what was formerly done by swinging pendulums, falling weights, and other timing devices, without using any apparatus outside the oscillograph. It makes unnecessary a special contactor, that has a time lag which agrees with that of the shutter, for closing the circuit which starts the transient.

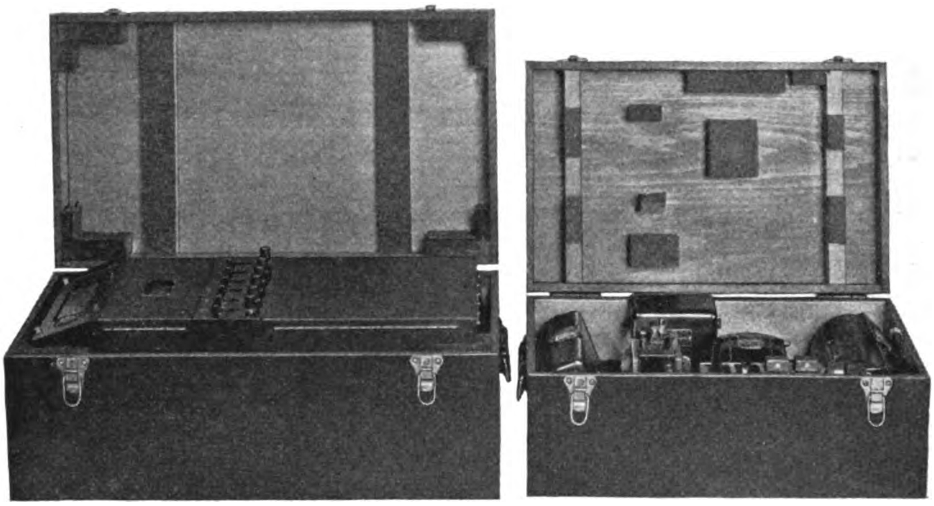


Fig. 8. Six-element General-purpose Oscillograph Equipment in Protective Carrying Cases

Accessories

Accessories, such as spare fuses for the vibrator circuits, spare lamps, damping liquid, belts, and repair parts for vibrators are conveniently stored in a drawer under the galvanometer compartment as shown in Fig. 4. The spare galvanometers, film holders, motor unit, shunts, and parts which must be removed from the oscillograph for shipment, have places for storage in one of the protective carrying cases shown in Fig. 8; while the main oscillograph unit may be stored or carried in the other case. The whole equipment can be carried in these two cases in an automobile or in a Pullman section. Its total weight, including the continuous-drive film holder is 138 lb. The oscillograph alone weighs only 60 lb.

Applications

This oscillograph is particularly adapted for field tests on power systems, since it is so easily carried from place to place and since it can be operated from a portable six-volt storage battery. Very little time is consumed in making preparations for tests and since the film holders are daylight-loading, the films can be taken back to a permanent dark room for development. The oscillograph can be set on any desk or table, and, if necessary, can be operated on the top of its protective carrying case. It can be insulated from ground when testing on ungrounded systems, by placing the table, oscillograph, and battery on a small insulated platform.

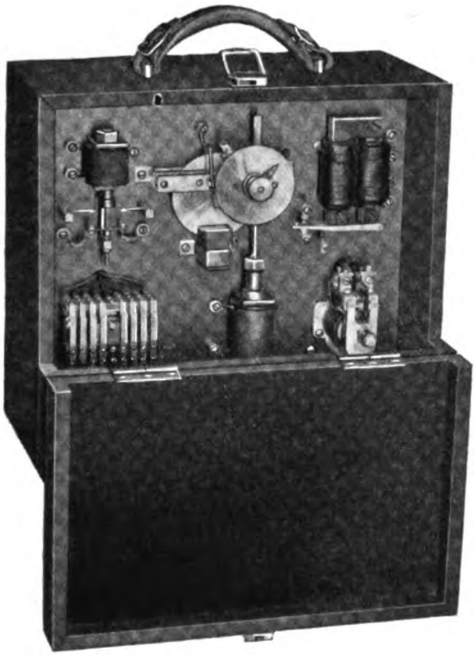


Fig. 9. Automatic Control Unit for Automatically Operating the General-purpose Oscillograph

It is not necessary to duplicate records from the main galvanometers for the purpose of establishing the time relation between the oscillograms when using two oscillographs simultaneously. The timing vibrators may both be used to record voltage impulses controlled by a time clock or other timing circuit for this purpose. The oscillographs may be operated side by side or at opposite ends of a transmission line if desired. In the latter case, a telephone circuit may be used for connecting the timing vibrators together during the test.

An oscillograph may be connected to operate automatically upon occurrence of a surge producing excessive current in one line or to ground. An automatic control unit, Fig. 9, has been designed having relays which start the oscillograph when the neutral current reaches a predetermined value and which control the duration of operation.

Although so well suited for field tests, this oscillograph meets the requirements for the most extensive laboratory investigations with a flexibility which has never before been available. It requires but a few minutes to change from one arrangement of records on a film to an entirely different one including records of current, voltage, power, pressure, vibration, or travel of moving objects or parts of machines. If it is not convenient to operate from storage batteries permanently, an a-c. motor unit adapts the oscillograph to operation from 110-120 volts a-c. Great variations in length of time covered by a record are possible, and distinct records have been obtained with film speeds up to 1100 ft. per min. using the incandescent lamp as a light source. An arc lamp and rheostat can be used in cases where the rate of beam travel across the film is higher. To use the arc lamp it is only necessary to remove the incandescent lamp with its lens from the oscillograph and set the arc lamp on the table as with older oscillographs.

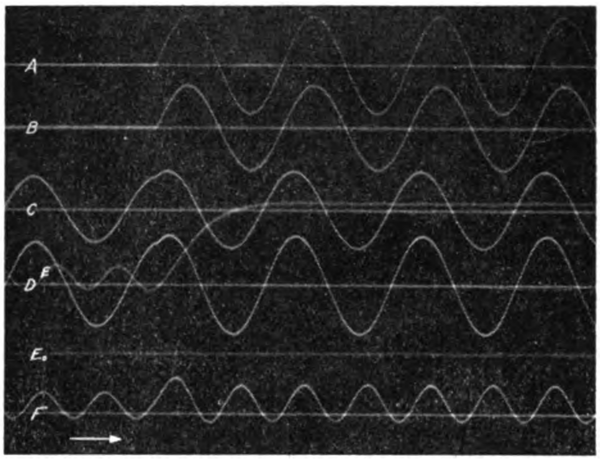


Fig. 10. Section of a Record 11 in. Long Taken at a Film Speed of 450 ft. per min. in the Magazine Film Holder, Showing (*A*) and (*C*) Voltage, (*B*) and (*D*) Current, (*E*) Three-phase Power, and (*F*) Single-phase Power. With this type of magazine film holder, records have been made at speeds as great as 1100 ft. per min.

The oscillograms in Figs. 10, 11, and 12 give an indication of the clearness of records produced by this oscillograph. Fig. 10 is typical of records made with the magazine film holder, having been taken at a film speed of 450 ft. per min. Satisfactory records have been obtained with this film holder up to 1100 ft. per min. Fig. 11 is a section from a five-foot oscillogram taken with the continuous-drive film holder at 45 ft. per min., and Fig. 12 from a ten-foot record taken with the same film holder at 20 ft. per min.

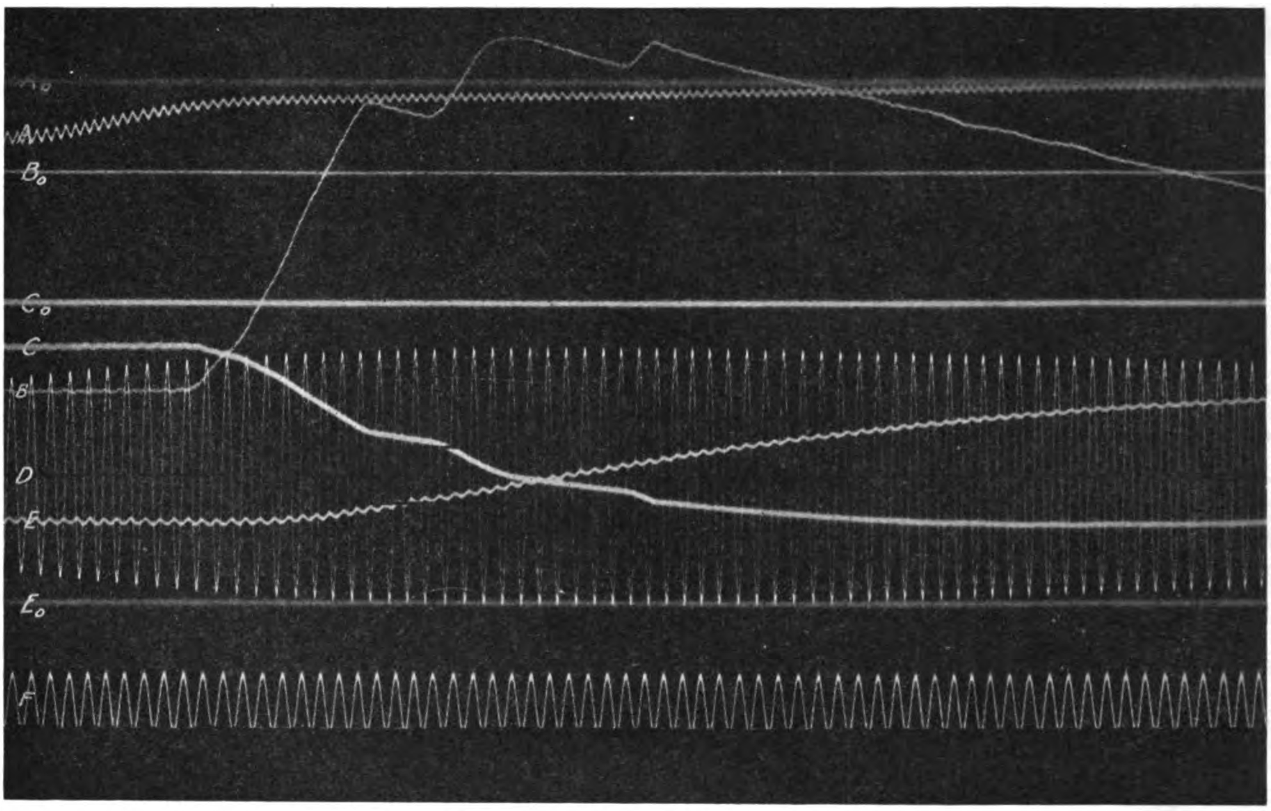


Fig. 11. Section of a Five-foot Record Taken at a Film Speed of 45 ft. per min. in the Continuous-drive Film Holder. This illustration shows the clearness of the records, and use of the zero mirrors (A_o), (B_o), (C_o), and (E_o)

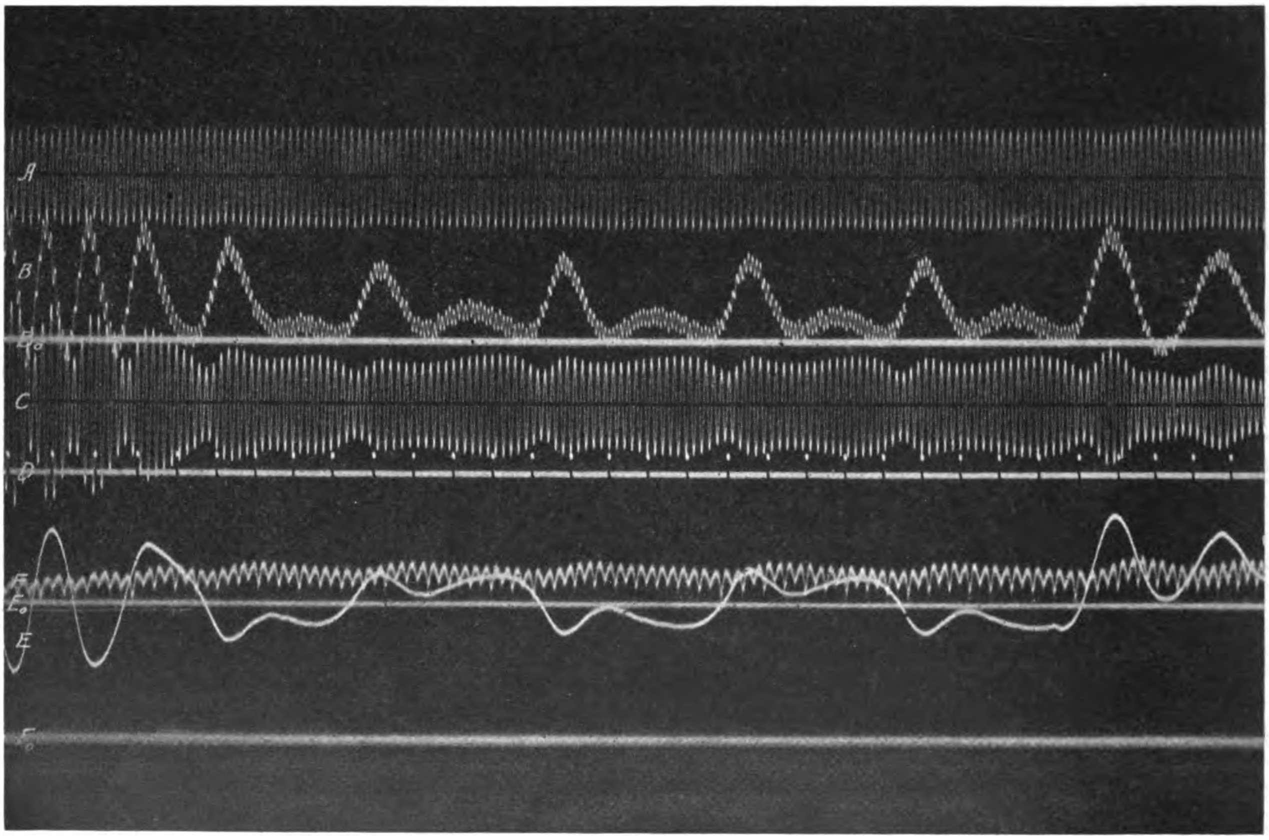


Fig. 12. Section of a Ten-foot Record Taken at a Film Speed of 20 ft. per min. in the Continuous-drive Film Holder. The record shows: (A) line voltage, (B) three-phase power, (C) current, (D) revolutions, (E) current in short-circuited field winding, and (F) speed of motor being tested. The records of two types of zero indicators are also shown: one in (A) and (C), and the other by (B_o), (E_o), and (F_o): Each deflection in Curve (D) marks one revolution of the motor under test

TWO-ELEMENT PORTABLE OSCILLOGRAPH

There has been a demand for a very small oscillograph which is completely self-contained and which does not require a skilled operator. Such an oscillograph has been successfully developed. Its performance is remarkable.

This oscillograph, Fig. 13, is a truly portable instrument since it weighs but 30 lb. It is mounted in a walnut case 18½ in. by 10 in. by 9 in. high, including a compartment for carrying the film holder. All controls are mounted on a top panel to give maximum convenience in operation and are protected from damage when the cover is closed. The oscillograph is completely self-contained and is almost as simple and convenient in adjustment and in operation as an ordinary portable indicating instrument.

The principal application of this oscillograph is for viewing the wave shapes of recurrent phenomena. When desired, use can be made of the film holder to take a very inexpensive record of anything which can be seen on the viewing screen. A transient may be seen if it is not of too short duration and the portion corresponding to a single movement of the light beams across the film may be recorded. Fig. 14 shows the oscillograph with the film holder in its operating position, while Fig. 13 shows it with the viewing screen in place. A folding hood for shielding the light from the viewing screen makes possible the use of the instrument in a brightly lighted room.

Since this oscillograph will operate equally well in any position, it may be placed on its side as shown in Fig. 15 with the panel and viewing screen in a vertical position. In this way it is particularly adapted for lecture-room demonstration. The waves on the screen may be seen at a distance of 20 ft. if the portion of the room in which the oscillograph is located is sufficiently darkened.

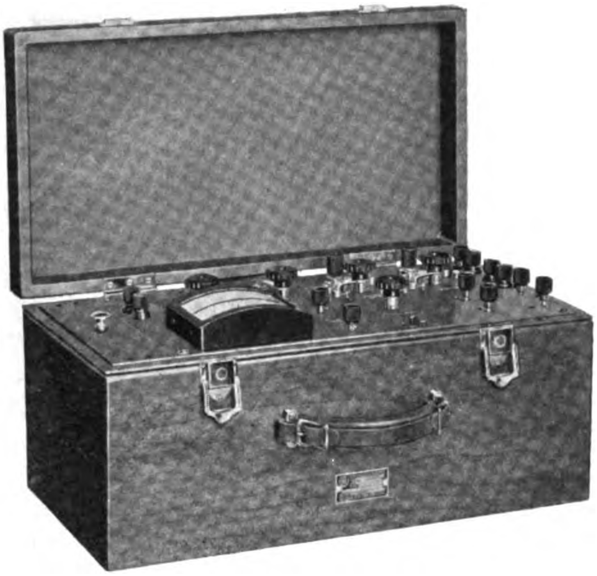


Fig. 13. Two-element Portable Oscillograph with Viewing Screen in Place

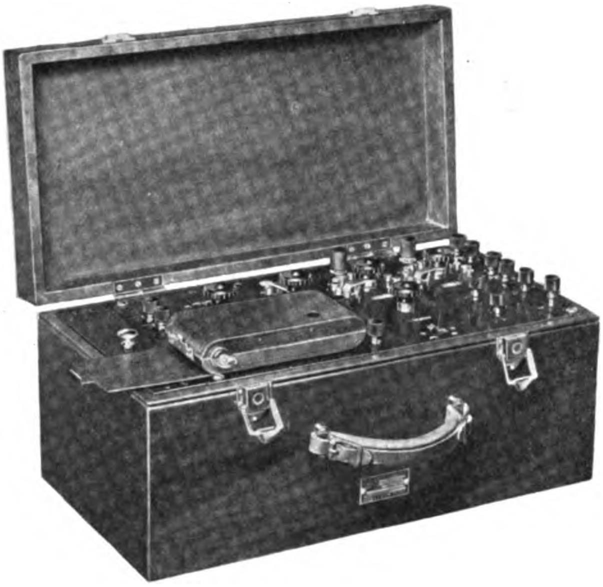


Fig. 14. Two-element Portable Oscillograph with Film Holder in Place

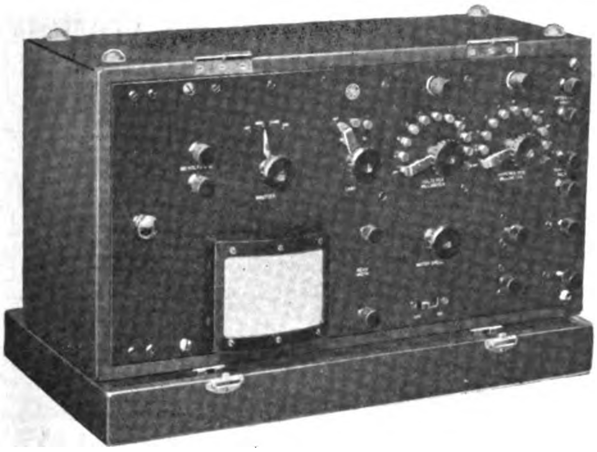


Fig. 15. Two-element Portable Oscillograph with Panel in Vertical Position for Lecture-room Demonstration

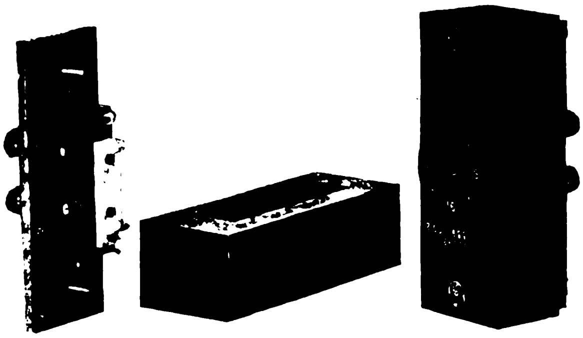


Fig. 16. Self-contained Oscillograph Galvanometers. One is shown with its vibrator removed

Galvanometers

This oscillograph has two permanent-magnet galvanometers of the same general design as those used in the general-purpose oscillograph. These are shown in Fig. 16, one having its vibrator removed from the cell formed by the magnet. These vibrators have a natural frequency undamped of 3000 cycles per second and a sensitivity of two milliamperes per millimeter deflection on the screen.

Although the two galvanometers are exactly alike and interchangeable, one is arranged for potential and the other for current measurement. The former is provided with a series rheostat for use up to 220 volts with each point calibrated in volts per millimeter deflection on the viewing screen; while the latter has a variable rheostat shunted across it, capable of carrying up to seven amperes, calibrated in amperes per millimeter deflection on the screen.

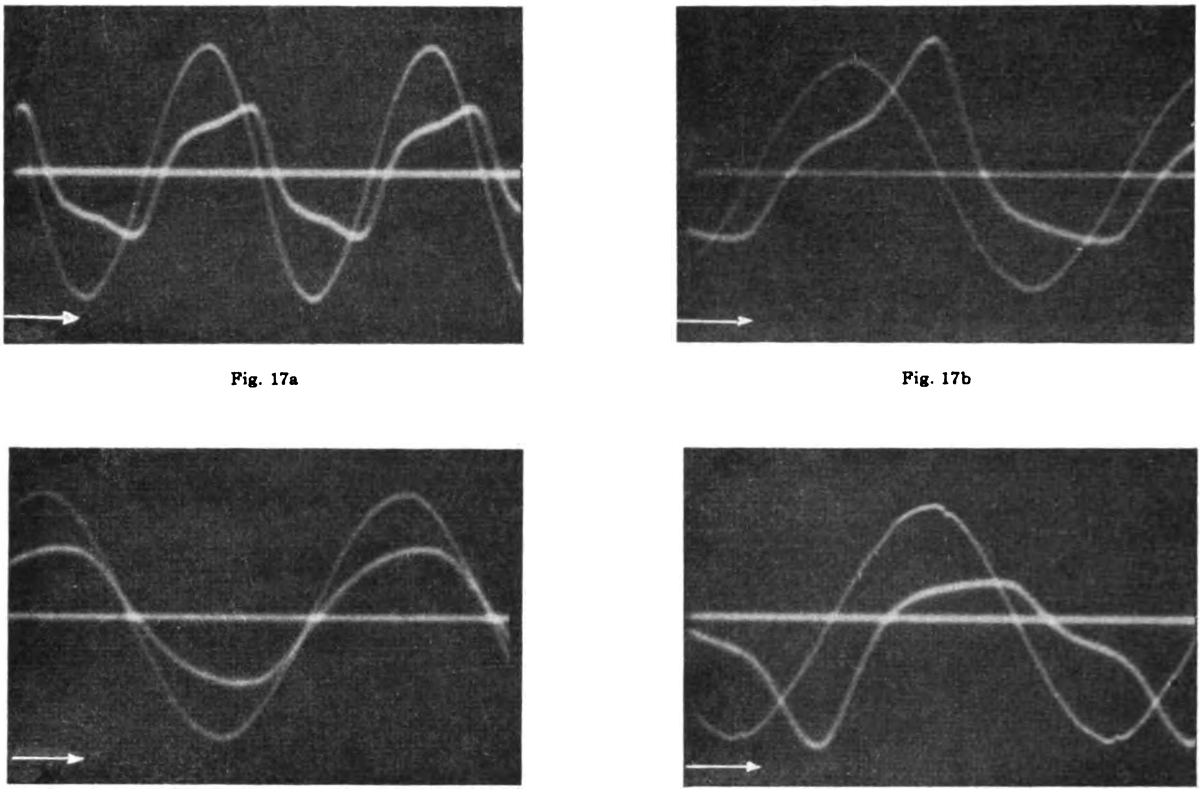


Fig. 17a

Fig. 17b

Fig. 17c

Fig. 17d

Fig. 17. Records Illustrating Application of Two-element Portable Oscillograph to Transformer Testing, Showing Wave Shapes of Voltage and Current. The records are 2 ½ in. by 3 ½ in. in size

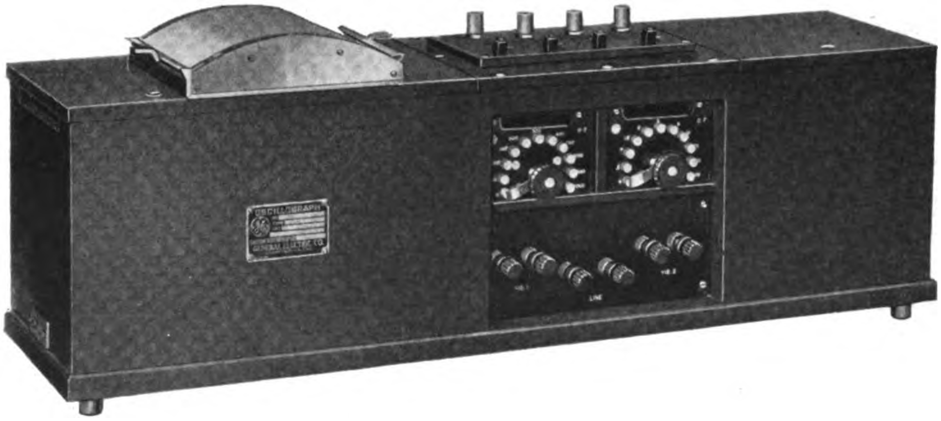


Fig. 18. Continuous-viewing Oscillograph Showing Viewing Screen and Control Panels

Power for Operation

The power required for operation may be obtained from any 110-120-volt a-c. lighting circuit. This operates at 6-8-volt, 32-cp. automobile headlight lamp through a suitable transformer, as well as the variable-speed motor which drives a rotating shutter and an oscillating mirror for extending the waves along the time axis.

Records

The tracing screen is 2½ in. by 3½ in. and six photographic records may be made on a standard "Brownie" No. 2 film. The traces are so sharp that small details can be easily examined. Fig. 17 shows oscillograms taken with this instrument of primary voltage and magnetizing current in a transformer.

CONTINUOUS-VIEWING OSCILLOGRAPH

As oscillographs are used more and more in industrial processes, the design of these can be made more directly applicable to individual applications. One of these is the application to magnetic-analysis work which requires an oscillograph that will show wave forms on a screen, is designed for continuous operation, and can be used by operators not particularly skilled in instrument use.

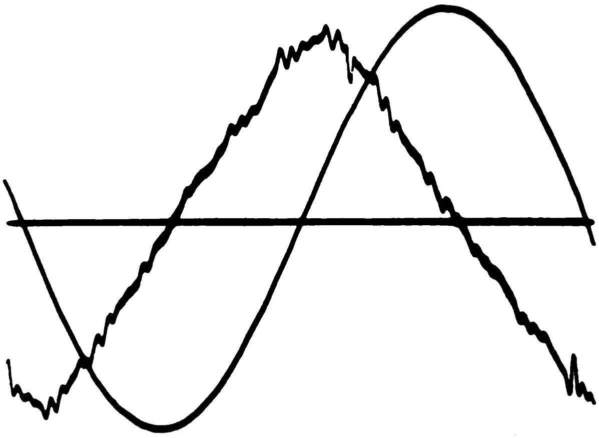
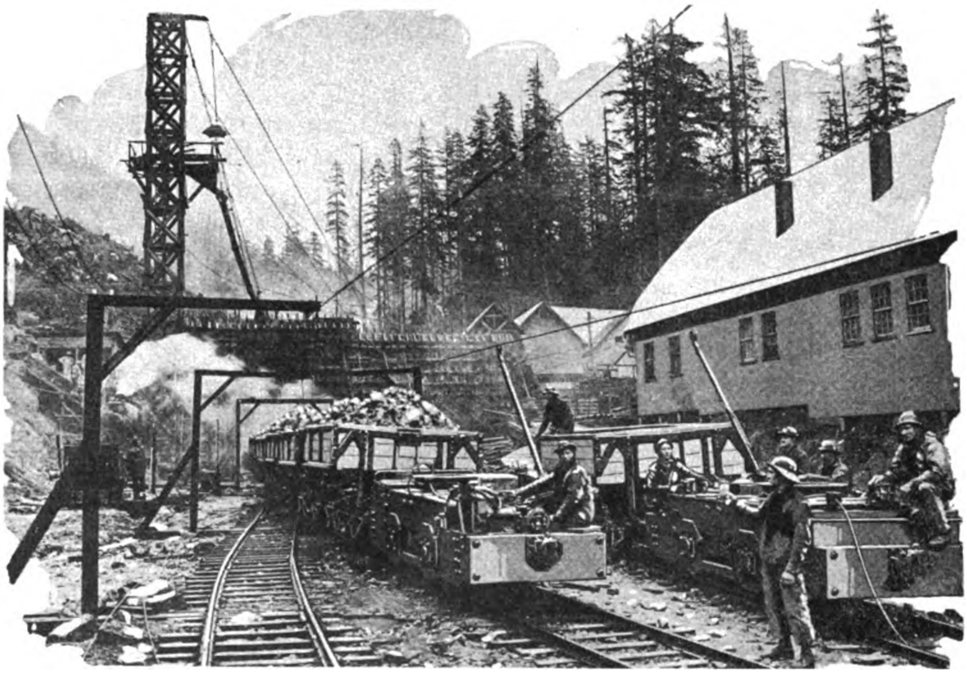


Fig. 19. Wave Shapes of Voltage Impressed on a Condenser and the Resulting Current as Recorded in Their Proper Phase Relation on Sensitized Paper When Using the Continuous-viewing Oscillograph. The record is 5 in. by 7 in.

Such an oscillograph is the continuous-viewing instrument shown in Fig. 18. It is designed for observing the waves from two permanent-magnet galvanometers on a screen 5 in. by 7 in. Its galvanometers are similar to those shown in Fig. 2. A self-starting single-phase synchronous motor, operating from a 110-120-volt lighting circuit, drives the oscillating mirror that projects the light beams on the screen. These waves will appear stationary on the screen if the a-c. source used to operate the synchronous motor is the same as that connected to the galvanometers. The waves may be traced if desired or may be photographed, as in Fig. 19, if sensitized paper is placed over the screen and the oscillograph is used in a dark room. This gives a record of wave shapes and phase relations which is inexpensive and yet is satisfactory for analysis.

This oscillograph, including the motor unit and vibrator rheostats, is mounted in a walnut case approximately 31½ in. by 8 in. by 10 in. high. The complete instrument weighs 47 lb. The same interchangeability of galvanometers and of vibrator rheostats is possible as in the six-element oscillograph. Also, the same lamp is used and many features are included which result in simplicity and safety of operation.



Principles of Selsyn Equipments and Their Operation

Principles Involved—Selective and Multiple Operation—The Differential System—Mechanical Construction—Applications

By L. F. HOLDER
Aeronautics and Marine Engineering Department
General Electric Company

General Theory and Description

A SELSYN system includes small self-synchronous instruments used as an electrical means of transmitting accurate angular motion between two or more remote devices which cannot conveniently be mechanically interconnected. The accuracy of the motion transmitted varies with the amount of torque required by the load, the size of Selsyn instruments used, and the acceleration and operating speed of the system.

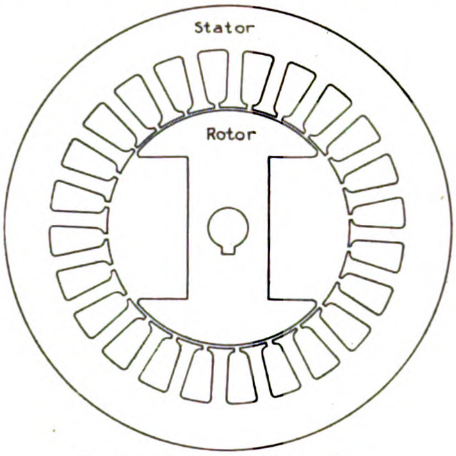


Fig. 1. Rotor and Stator Punchings

A Selsyn device is mechanically a miniature bipolar rotating-field three-phase alternator. The rotor is wound with a single-phase concentrated winding; the stator, with a three-circuit distributed Y-connected winding. The shape of the rotor and stator punchings is shown in Fig. 1. Electrically, in normal operation, the Selsyn device acts as a transformer and voltages and currents existing in the instrument are all single-phase. The rotor winding is excited from an alternating voltage source. By transformer action, voltages are induced in the three elements of the stator winding, the magnitude depending upon the angular position of the rotor.

The simplest of the Selsyn systems consists of two instruments connected as illustrated in Fig. 2. The two rotors are excited from a common source and the stator leads are interconnected $S1$ to $S1$, $S2$ to $S2$, and $S3$ to $S3$, respectively. Assuming both rotors free to turn, they will take such a position that the voltages induced in the two stators are of balanced magnitude and displacement. Under this condition of stator-voltage balance between the two instruments there is no circulating current in the stator windings. Now, if the rotor of one Selsyn device is displaced by a certain angle and the rotor of the other is held in its original position, the stator-voltage balance is altered and a circulating current will flow in the windings. This circulating current reacting on the excitation flux provides a torque tending to turn the rotors of the machines to a position where the induced stator-voltages are again equal and opposite. Thus, with both rotors unrestrained, any motion given to the rotor of one Selsyn device will be transmitted to and duplicated by the rotor of the second, and we thus have a system of electrically transmitting mechanical motion.

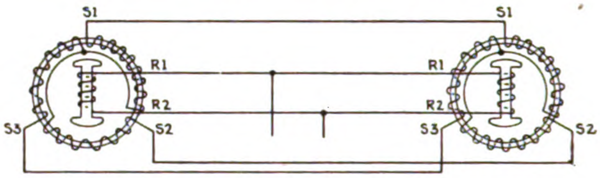


Fig. 2. The Simplest Selsyn System

It can be shown by mathematical analysis that the electromagnetic coupling between the two rotors is such that a load placed on the rotor of the receiving Selsyn device will cause it to lag behind the transmitting device by an angle which is dependent in size on the magnitude of the load. Fig. 3 illustrates the torque, excitation current, and induced stator current for various angles of displacement. It will be noted that at 180 deg. displacement the circulating stator current and the excitation current are at a maximum although the torque is of zero value. This point is very unstable and Selsyn devices of their own accord will never operate with this displacement, but will always synchronize when their rotors are excited. This is one of the superior characteristics of the Selsyn system over other schemes of electrical transmission of mechanical motion; the system is self-synchronous, that is, at the resumption of power after an interruption the Selsyn system automatically resets itself.

The Selsyn instrument draws but little power from the line and is designed for continuous excitation. The electrical design is based on the allowable temperature rise in the instrument. Since the excitation current and the circulating stator current increase with the magnitude of displacement, a Selsyn system must never have a displacement angle exceeding 20 degrees for more than a short period; otherwise, excessive heating and possible burnout of the windings may occur. Thus, in applying Selsyn equipments to a particular duty the torque requirements should be carefully studied and equipment of ample size should be selected.

It has been the custom to call the Selsyn instrument which is used as the transmitter, a Selsyn generator, and the remote or receiving instrument, a Selsyn motor. The one does not generate electrical power nor does the other transform it into mechanical motion. The Selsyn system merely transmits mechanical motion and, neglecting friction losses, the mechanical power output of the receiver is exactly equivalent to the mechanical power input to the transmitters.

Electrically, the Selsyn generator and motor are identical. Physically, they differ in that the motor has mounted on its rotor shaft an oscillation damper. This damper consists of a lead ring mounted by friction plates on a sleeve which is fastened to the shaft. The lead ring has a large amount of inertia and can be rotated on the sleeve only with considerable difficulty. Any violent oscillation of the rotor rotates the sleeve, a motion which the lead ring cannot follow immediately because of its inertia. Thus, there is a large dampening effect on the oscillating rotor and its movement is quickly stopped. This inertia damper is illustrated in Fig. 4.

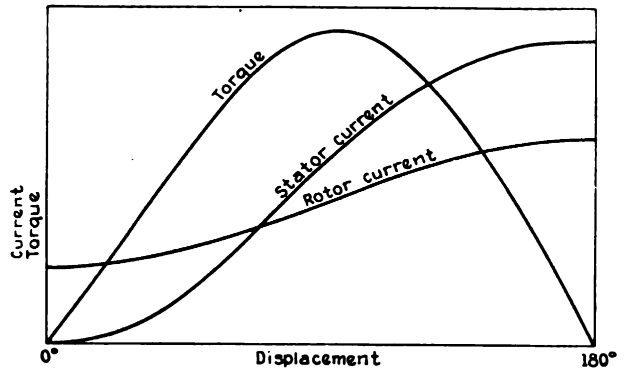


Fig. 3. Torque, Excitation Current, and Induced Stator Current for Various Angles of Displacement

Selective Operation

The next step after the single transmitter-receiver Selsyn system is that where several receivers are actuated one at a time from a single transmitter through some suitable means of selection such as a transfer switch located near the transmitter. Here the Selsyn system demonstrates its important advantage of being self-synchronous. Any receiver is synchronized with the transmitter and can be operated at will, without the necessity of presetting, by a mere setting of the selector switch.

Mutiple Operation

The Selsyn system may also be used for multiple operation; that is, several Selsyn receivers may be operated by a single Selsyn transmitter. The operation is in general the same as in the single transmitter and receiver system. There are, however, some additional inherent peculiarities that should be noted. In the system consisting of a single transmitter and receiver each of the same physical size, the torque-angle characteristic is considered as standard for that size of Selsyn frame. Now, if two receivers are operated from a single transmitter, all of the same frame size, the torque (T_R) developed by each receiver at a given angle of displacement will be only ⅔ of the standard value of torque (T_T). If there are three receivers, the torque of each is still further reduced to ½ T_T, and for any number of receivers $T_R = T_T \times \frac{2}{N+1}$ where N is the number of receivers. For this reason it is standard practice in multiple Selsyn systems to use as the transmitter a device of larger frame size than the receivers, and of such characteristics that each receiver will develop its standard torque. Another peculiarity of the multiple Selsyn system where the friction load on the separate Selsyn receivers may vary is that the lightly loaded Selsyn receivers assist the transmitters to keep the more heavily loaded ones in synchronism, and much greater than standard torque may be developed by the more heavily loaded instruments. This is accompanied, however, by an increase in magnitude of the general system displacement angle.

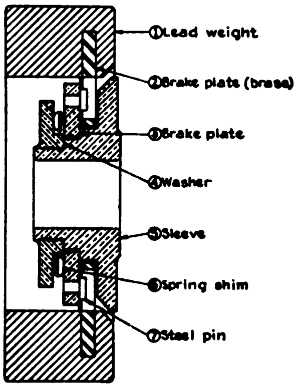


Fig. 4. Inertia Damper for Selsyn Motor

Series Operation—The Differential Selsyn

Series and series-multiple types of Selsyn systems are also used. These involve the use of the differential Selsyn device, the operating characteristics of .which must be considered to get a correct understanding of its use.

The differential Selsyn device is identical in construction with the standard Selsyn instrument except that its rotor punching differs (see Fig. 5) and the rotor has a distributed three-circuit Y-connected winding. Three collector rings instead of two are also necessary to bring out the rotor winding leads. Its physical form is thus seen to be that of a miniature three-phase wound-rotor induction motor. However, in normal operation its function is that of a single-phase transformer and three-phase voltages and currents do not exist. The rotor may or may not be equipped with a damper and the designation of differential Selsyn generator or motor distinguishes this feature in the same manner as in the standard Selsyn devices.

The simplest differential Selsyn system is shown in Fig. 6 and consists of three units—two standard and one differential. The stator winding of the differential is connected phase for phase to the stator of one standard Selsyn unit; the rotor winding is connected phase for phase to the stator of the other standard Selsyn unit. Since the differential device does not have a connection directly to the source of excitation, its exciting current must be furnished through one or both of the standard Selsyn devices to which it is connected. The general practice is to supply this excitation on the stator winding only. It is obvious that, since the standard Selsyn device connected to the differential stator supplies this excitation current, it must be designed to carry this extra load without overheating. A special design of standard apparatus is used, commonly designated "Selsyn Exciter," which may function in the system either as a transmitter or receiver, and sometimes in more complex systems merely floats on·the system as an excitation supply to the differential.

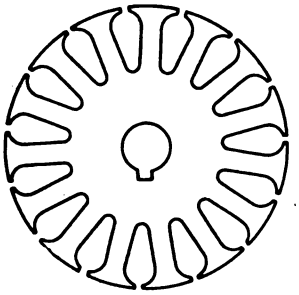


Fig. 5. Punching for Differential Device

The operation of the differential Selsyn device is very similar to that of the standard one. The voltage distribution in its stator winding is the same as in the stator winding of the Selsyn exciter. The distribution of the exciting flux is likewise the same. Also, the impressed voltage distribution in its rotor winding is the same as in the stator of the standard Selsyn unit to which it is connected. The induced rotor voltage distribution is, of course, determined by the distribution of the exciting flux. The point of equilibrium is such that the impressed and induced voltages in the rotor winding of the differential Selsyn unit are equal and opposite. Under this condition there is minimum current flow. Disturbance of this condition will set up a circulating current which will react on the excitation flux, producing a torque tending to restore the equilibrium condition. It is apparent that the disturbance can be set up by moving the rotor of any of the three Selsyn devices. If any one of the three is fixed in position and a second one displaced a certain angle, the third, being free to rotate, will turn through the same angle. The direction of rotation can be reversed at will by reversing any pair of leads on either the rotor or stator windings, respectively, of the differential Selsyn unit. If any two of the devices are rotated simultaneously, the third will rotate through an angle equal to the algebraic sum of their movements, the algebraic sign being dependent not only upon the physical direction of rotation of the rotors but also upon the phase rotation of the windings.

Thus we have a means of controlling a Selsyn receiver from two separate sources at will and, if the angle of rotation of the transmitters is limited, a self-synchronous means. A Selsyn system of this kind can be indefinitely extended in a wide variety of combinations of transmitters and receivers. Successful systems are in present use where three differential Selsyn units in series are linked between the primary transmitter and receivers. In these more complex systems, it is customary to relieve the Selsyn exciters from the necessity of furnishing the total exciting current. This is done by connecting balanced static capacitors across the stator leads of the differential. These capacitors are of such a rating that they take a leading excitation current exactly equal to the lagging excitation current required by the differential, with the result that the Selsyn exciter is only required to furnish the power component of current which as a general rule will be less than one-tenth of the total excitation current.

Effect of External Impedance

In the majority of cases where the distance between Selsyn units is short, the impedance of the connections can be neglected. Frequently, however, long connecting lines are necessary and, when the resistance of these lines becomes comparable with the resistance of the Selsyn stator winding, both the magnitude and phase angle of the stator current are affected. This change reduces the torque output which can be obtained from the Selsyn instrument. For this reason, in long Selsyn systems the resistance of the interconnections is made as low as practical and Selsyn units are used with stator windings of a high value of impedance. The torque-resistance characteristic and the effect of increasing the stator impedance are illustrated in Fig. 7. For all except very special installations this method will suffice, although it is possible to obtain still better results by employing still higher voltages on

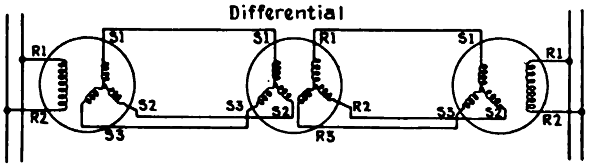


Fig. 6. Connections for Simplest Differential Selsyn System

the stator interconnections by the use of special transformers between the lines and Selsyn units.

As has been mentioned previously, all Selsyn units in a Selsyn system must be excited from the same alternating voltage source and, in case of multi-phase supply, from the same phase of the supply. In some instances it is necessary to run lines to the remote Selsyn unit to supply this excitation. If these lines are long, their resistance will be large and there will be not only a considerable voltage drop in them but also an excitation current phase displacement in the remote Selsyn unit. Since the torque output is proportional to the square of the excitation voltage, and change in internal phase relationships in the system creates dangerous circulating currents, means should be provided to remedy the situation when excitation must be remotely supplied. The standard means of raising the terminal voltage is to insert a small auto transformer in the line to compensate for the *IR* drop. The change in internal phase relationship in the Selsyn system can be taken care of only by the insertion of a balancing impedance in the rotor circuit of the near Selsyn unit. There is, of course, a reduction in torque output available from the system, but this must be accepted since the phase unbalance if not remedied may create sufficient circulating current in the Selsyn units to cause excessive heating and consequent failure. See Fig. 8.

Voltage Ratings

Standard commercial Selsyn units are wound to be excited from 110 volts, 60 cycles, but special forms are wound for other voltage and frequency ratings. The standard commercial stator voltage rating is 55 volts, but higher-impedance stator windings are commonly wound for 110 and 220 volts. In any Selsyn system, of course, the respective rotor and stator windings of all Selsyn units in the system must have the same electrical characteristics; that is, a unit with 55-volt stator winding cannot be operated with another having a 220-volt stator winding.

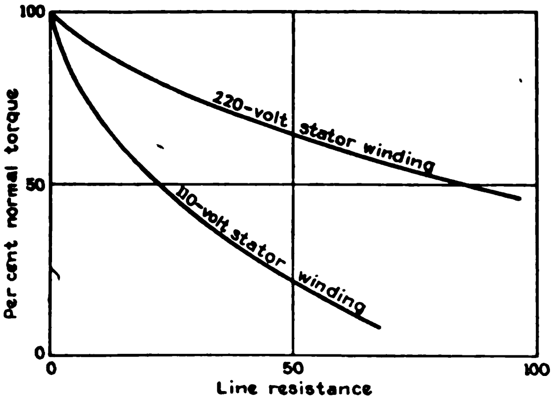


Fig. 7. Torque-resistance Characteristic and Effect of Increasing Stator Impedance

Use of Ground for Interconnection

In the simple Selsyn system where the excitation is remotely supplied, five wires are necessary between the transmitter and receiver. If the resistance of these wires is low, it is possible to omit one of them by using one as a common rotor and stator connection. If the resistance value is appreciable, however, the accuracy of the system is affected. It has also been suggested to use a ground return for one of the stator leads, but this is never advisable on any installation; since ground resistance is variable, there is an unbalance of the resistance of the stator circuit and extraneous voltages may be picked up because of ground currents. The varying and uncertain characteristic of the stator phase using the ground return would cause erratic operation of the system.

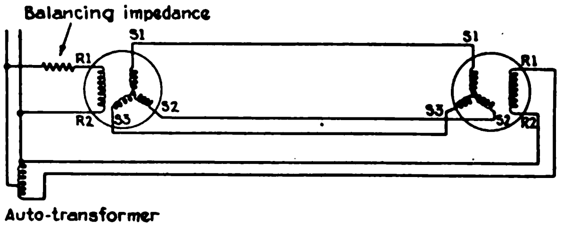


Fig. 8. Balancing Impedance

Use of Telephone Cable for Interconnection

The use of conductors in the same cable with those used for communication is entirely practical for Selsyn interconnections. Certain requirements, however, must be met in regard to noise interference, permissible voltage and currents, and necessary insulation. Filtering equipment is generally required between the source of excitation and the Selsyn apparatus. This must be of such design that there will be no appreciable rise in terminal voltage of the filter unit in case of open circuit and that there will be a reduction of at least 90 per cent in all harmonics above 300 cycles in going through the filter. Ground connection on the circuit electrically connected to the telephone conductors is not permitted and insulating transformers must generally be used to prevent the possibility of high voltages (approximately 3000 volts) being placed on the telephone wires. Operating voltages and currents must not exceed 120 volts and 350 milliamperes, respectively.

Power Line Interference

Where Selsyn unit interconnections closely parallel power lines, proper transposition of lines is necessary to eliminate inductive interference. It may also be advisable in certain cases to ground all three of the Selsyn unit stator interconnections through high resistance (order of 1000 ohms) to prevent the accumulation of electrostatic voltages. In making this ground, three resistors of equal value should be used, connected in *Y* and grounded at the *Y* point.

Mechanical Construction of Selsyn Units

The usual commercial design of Selsyn unit is illustrated in Fig. 9 and consists of a stator punching assembly and winding, a rotor punching assembly and winding, a slip-ring collector, brush assembly, ball bearings, and cast end shields. The rotor turns on ball bearings mounted in the end shields and the stator and end shields are firmly clamped by three bolts in a rabbeted fit. By this means accurate centering of the rotor and stator punching assemblies is obtained. The commercial design is ordinarily foot-mounted, as illustrated, but is also built for flange and trunnion mounting. The collector in most of the later designs is external to the collector end shield and is covered with an easily removable inspection cap. The collector rings and brushes are both made of special materials to meet the unusual requirements of a low-friction non-corrosive unabrasive perfect electrical contact. Leads of both rotor and stator windings are brought out and after testing are tagged with the correct phase rotation. The Selsyn instrument is exceptionally compact and strong, and must pass rigorous noise and accuracy tests.

Special Selsyn Units

Many other types of Selsyn units have been developed, including jeweled-bearing units for precision and instrument work, high-accuracy Selsyn units with restricted rotor rotation and special collector leads, and some of extremely compact design to meet limited overall dimensions.

Applications

The Selsyn system in the commercial field has three primary functions: remote signaling, remote control, and transmission of synchronous power. The remote signaling may be audible or visual or both; the remote control, either manual or automatic. Scores of various and ingenious adaptations have been and are being made of both principles. When used primarily to transmit synchronous power, the Selsyn system is rotated continuously at varying speeds, preferably not exceeding 1800 r.p.m., the amount of power transmission being a function of the size of units used and the speed at which the system is rotated. The theory of operation of such a system is complex because of the presence of rotating as well as pulsating voltages, and of acceleration and inertia forces. Such a system requires detailed study before being adapted for a definite duty.

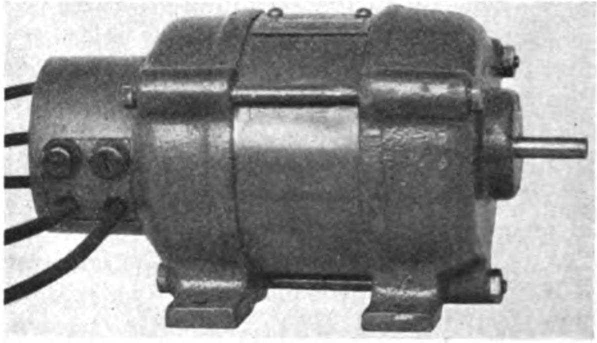
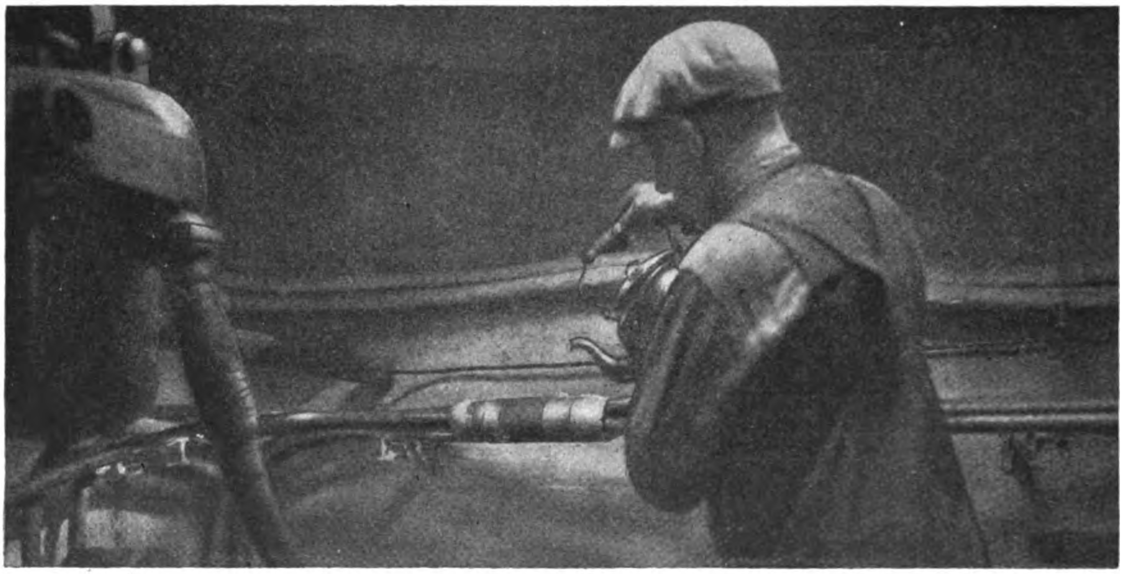


Fig. 9. Selsyn Generator



The Efficiency of the Rice-Kellogg Loud Speaker

By DR. ELLSWORTH D. COOK

Formerly with the Radio Engineering Department, General Electric Company
Now with the United Research Corporation, Long Island City, N. Y.

The author presents two methods of arriving at the efficiency of this type of loud speaker. With the widespread use of these devices, their efficiency and approved methods of determining this performance factor are matters of worthwhile consideration.—EDITOR

THE introduction of loud speakers capable of developing considerable sound energy from electrical energy for commercial uses gave rise to many problems which were not considered particularly important in the type of loud speakers used in the home. The measurement of the efficiency of these loud speakers is one of these problems. It is complicated by the lack of simple yet reliable acoustic measuring devices. Two methods are considered herein for obtaining this efficiency. The particular type of loud speaker considered in this article was developed by Messrs. Rice and Kellogg (1) and is popularly called an "electro-dynamic cone loud speaker," assembled and disassembled views of which are shown in Figs. 1 and 2, respectively. The efficiency of this device has been generally believed to be about two per cent over the entire audio-frequency scale. This figure was obtained by estimating the force developed by the moving coil and the radiation resistance of a plunger in an infinite wall. However, a careful test analysis has shown that the average value obtained in this manner is too low. The assumptions upon which these calculations were based did not correspond to the operating conditions of an actual loud speaker. As a consequence, this figure is at the best a rough estimate.

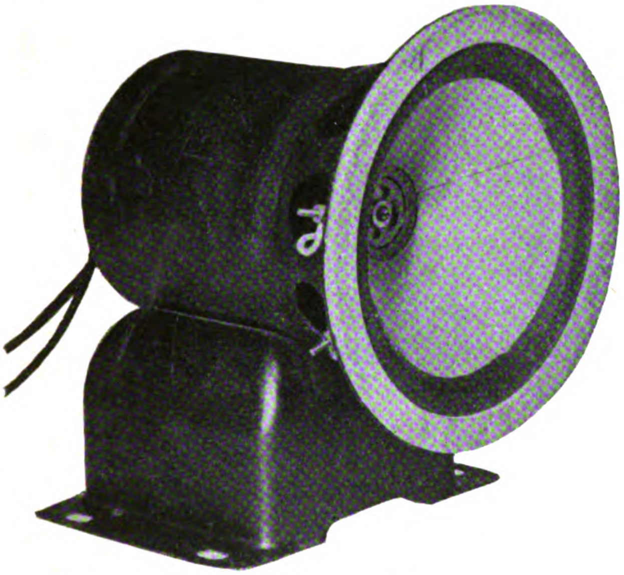


Fig. 1. The Speaker Unit of the Rice-Kellogg Loud Speaker

The First Method

The first method is an indirect one, as the quantities are measured entirely in the electrical system. The results thus obtained have been checked by measuring corresponding factors in the mechanical system. The agreement is better than expected, considering the difficulties encountered in such measurements. The first method is useful in those cases that are not characterized by severe "breaking up" of the cone into zones vibrating in complex modes, since it was developed on the assumption of a motion approximately that of a rigid plunger. The values obtained in frequency bands where the cone moves essentially, though not absolutely, as a piston are reasonably close to the true efficiency. It is fortunate that severe "breaking up" does not take place everywhere throughout the entire audio-frequency spectrum, though this action does take place in regions which have not been generally suspected.

In this first method, the measurements are made on an impedance bridge of careful design and construction (Fig. 3). It must carry the current for the moving coil of the loud speaker without change in resistance due to temperature change, frequency, or mechanical causes.

The ratio arms of the bridge were fixed at 15 ohms, which is equal to the average resistance of the cone-coil circuit in the more important range of frequencies. It was estimated at first that the permissible error in resistance readings could not exceed 0.0001 ohm, but the actual results showed efficiencies higher than expected and consequently reduced the severity of such a requirement. A balance on the bridge was indicated by a grid leak and condenser type of tube voltmeter fed by a three-stage high-quality amplifier. The coupling units used in this amplifier were of the resistance and capacity type, and the input system was bridged across the balance points of the bridge in such a manner that it did not affect the balancing of the bridge. Some of the measurements were made in a partial vacuum of approximately 0.50 cm. of mercury, absolute pressure, as read by the differential gauge shown in Fig. 4. The audio-frequency power used to actuate the loud speaker was supplied by a resistance-coupled power amplifier capable of delivering 50 watts of undistorted power. The amplifier in turn was driven by an oscillator having an exceptionally good wave shape.

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(1) "Notes on the Development of a New Type of Hornless Loud Speaker," by Chester W. Rice and Edward W. Kellogg, *A.I.E.E. Trans.*, 1925, Vol. 44, p. 461.

It is believed that the bridge method of determining efficiency as here described is essentially new and that the results given are the first ever obtained for the Rice-Kellogg type of loud speaker. The work was begun early in 1926, but because of many practical difficulties encountered it was not satisfactorily completed until late in 1927. Most of the measurements had to be made when operations in the surrounding factory buildings had ceased, thus minimizing extraneous noises which could not otherwise be completely excluded from the large room in which the measurements were made.

When the cone vibrates in a vacuum, the load due to the reaction of the air is missing. However, the impedance as viewed from the cone terminals is made up of the actual cone impedance and the impedance which is due to the motion of the cone or the so-called "motional impedance." The latter impedance is measured by the ratio of the generated voltage, due to the motion of the cone, and the current in the cone coil. It is evident that if the cone coil is blocked, the impedance at the terminals of the cone coil is due to the electrical constants of that coil and to the existing core losses. Thus, it should be possible to evaluate the power expended in useful radiation, mechanical energy losses in the cone and its supports, copper loss in the cone coil, and the combined core and copper damper ring losses from the three impedance measurements: first, with the cone freely radiating; second, in a vacuum; and third, with the cone blocked.

The data obtained from the impedance bridge measurements were designated in the following manner:

$Z_e = (r_e + jx_e)$; electrical impedance of cone vibrating on the baffle.

$Z_b = (r_b + jx_b)$; electrical impedance of cone blocked.

$Z_v = (r_v + jx_v)$; electrical impedance of cone vibrating in a vacuum.

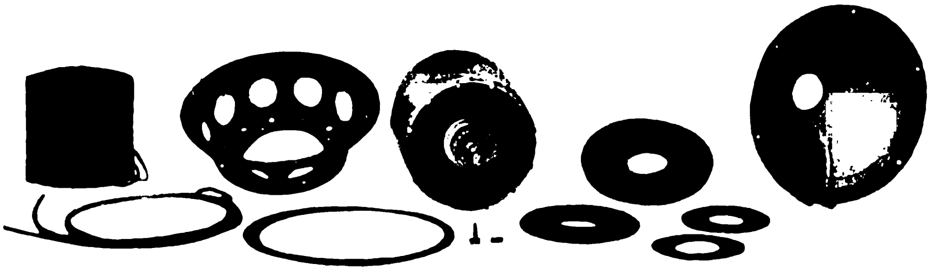


Fig. 2. The Parts of the Loud Speaker Shown in Fig. 1

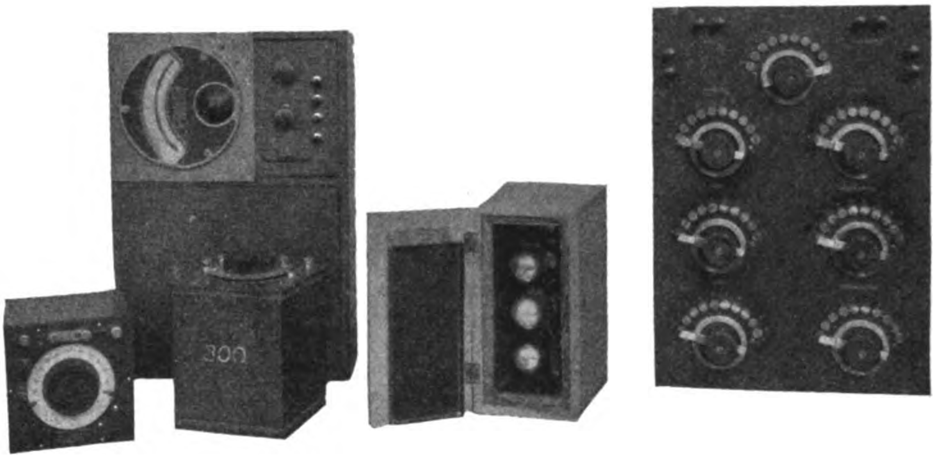


Fig. 3. Special Impedance Bridge and Auxiliary Equipment Employed in Making Efficiency Measurements According to the First Method Described

The derived mechanical data are:

$Z_c = (r_c + jx_c)$; mechanical impedance due to cone only.

$Z_a = (r_a + jx_a)$; mechanical impedance due to air load only.

$Z_m = (r_m + jx_m)$; total mechanical impedance $(Z_c + Z_a)$.

The power relations are:

$P_m = (\{r_a + r_c\} V_a^2)$; mechanical power supplied to the cone.

$P = (P_m + i^2 r_b)$; total power supplied to cone.

$P_r = (r_a V_a^2)$; power radiated in sound wave.

$\eta = (P_r / P)$; efficiency of loud speaker.

The impedance $Z_m = (Z_a + Z_c)$ assumes that the plunger moves as a piston, which is more nearly true at the lower frequencies than in the upper registers. Fortunately this action is at least approximated to a sufficient degree over the larger part of the more essential frequency range. If F_a is the central force on the cone when vibrating in free air and V_a the resultant central velocity, then $Z_m = \frac{F_a}{V_a}$. Suppose the flux density of the field in which the coil moves is β lines per sq. cm., the current in the cone coil is i abamperes, and the length of wire in this coil is l centimeters, then the central force on the cone is $F = (i\beta l)$ dynes. If the impedances are measured in ohms and the other variables are measured as have been described:

$$i^2 (Z_e - Z_b) = i^2 \left(\frac{\beta^2 l^2}{10^9 Z_m} \right) \tag{1}$$

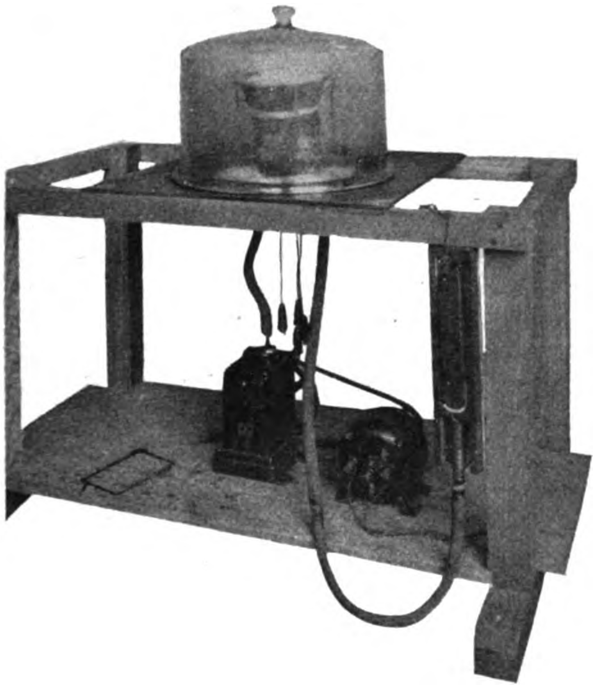


Fig. 4. Loud-speaker Unit Being Tested in Partial Vacuum

where the factor (10^9) compensates for the two systems of units used in Equation (1).

Therefore

$$(r_a + r_c) + j(x_a + x_c) = \frac{\beta^2 l^2}{10^9} \left\{ \frac{(r_e - r_b) - j\,(x_e - x_b)}{(r_e - r_b)^2 + (x_e - x_b)^2} \right\}$$

Designating

$(Z_e - Z_b)$ by Z_{eb}; and $(Z_v - Z_b)$ by Z_{vb}

we have

$$r_a + r_c = \left(\frac{\beta^2 l^2}{10^9 |Z_{eb}^2|} \right) (r_e - r_b) \tag{2a}$$

$$x_a + x_c = \left(\frac{-\beta^2 l^2}{10^9 |Z_{eb}^2|} \right) (x_e - x_b) \tag{2b}$$

In a similar manner, from measurements made on a freely vibrating cone in a partial vacuum and with the cone blocked, the mechanical resistance and reactance of the cone alone may be obtained. Thus:

$$r_c = \left(\frac{\beta^2 l^2}{10^9 |Z_{vb}^2|} \right) (r_v - r_b) \tag{3a}$$

$$x_c = \left(\frac{-\beta^2 l^2}{10^9 |Z_{vb}^2|} \right) (x_v - x_b) \tag{3b}$$

From these values, the reactions due to the air load may be found.

$$r_a = \frac{\beta^2 l^2}{10^9} \left\{ \frac{(r_e - r_b)}{|Z_{eb}^2|} - \frac{(r_v - r_b)}{|Z_{vb}^2|} \right\} \tag{4a}$$

$$x_a = \frac{-\beta^2 l^2}{10^9} \left\{ \frac{(x_e - x_b)}{|Z_{eb}^2|} - \frac{(x_v - x_b)}{|Z_{vb}^2|} \right\} \tag{4b}$$

In the final relations, r_{eb} will be substituted for $(r_e - r_b)$ and r_{vb} for $(r_v - r_b)$.

$$\eta = \frac{P_r}{P} = \frac{\left(\frac{r_a}{\beta^2 l^2} \right)}{\frac{(r_a + r_c)}{\beta^2 l^2} + \left(\frac{i}{\beta l V_a} \right)^2 r_b} \tag{5}$$

But

$$\left| \left(\frac{i}{\beta l V_a} \right) \right|^2 = \frac{|Z_m^2|}{\beta^4 l^4} = \frac{1}{10^9 |Z_{eb}^2|} \tag{6}$$

Hence, by Equations (2), (4), and (6),

$$\eta = \frac{r_{eb} - r_{vb} \left| \frac{Z_{eb}}{Z_{vb}} \right|^2}{r_e} \tag{7}$$

Since the central force on the cone for a given cone current depends directly on the flux density in the air gap, the efficiency of the cone as a converter of electrical energy to sound energy will depend upon this flux density. This fact is not apparent in Equation (7). However, it will be found that the magnitude of the various factors are affected by the flux density in any test determination of these values.

The first satisfactory data were obtained on two different sizes of cones; one a six-inch and the other a twelve-inch cone. These cones were mounted in a baffle, which was a flat surface four feet wide and five feet high in this case. The actual efficiency values obtained are shown in Fig. 5. It will be seen that there is a range of frequencies in which the efficiency curves are not shown. The results obtained for this region seemed doubtful and consequently they were not plotted. It was suspected that the cone was "breaking up" so badly in this region that the equations were not valid.

It is interesting to note that the average efficiency is higher than the previously accepted value of two per cent. It can be raised somewhat by the use of a more powerful field in the air gap. That the efficiency of the six-inch cone can be improved is confirmed by these curves, for over the range below about 3000 cycles, the twelve-inch cone has a higher average efficiency than the six-inch cone. This is due to an increased radiation resistance over this region. The gain in efficiency is, however, not as great as might be expected from a comparison of the radiation resistances for the two cones, and is also accompanied by a greater general departure from true piston action.

The "valleys" in the efficiency curve for the twelve-inch cone are more numerous than in that of the six-inch cone.

The apparent efficiency of the loud speaker is a matter which concerns the designer of the amplifier to some degree, since the output of a tube is limited more by its volt-ampere power limit than by the actual power consumed by the loud speaker. Fig. 6 shows the apparent efficiency of the same two loud-speaker units, the efficiencies of which were calculated and plotted in Fig. 5. Here again the twelve-inch cone shows somewhat higher average efficiency and a little less regular characteristics than the smaller cone.

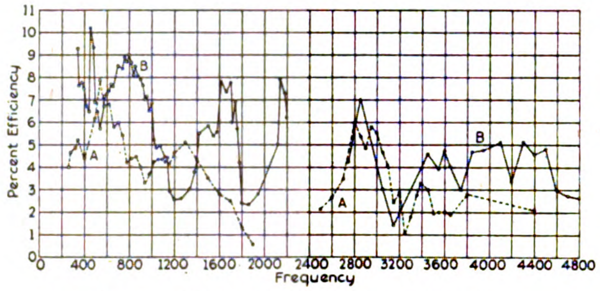


Fig. 5. Efficiency Curves of the Loud Speaker

A—With six-inch cone.
B—With twelve-inch cone.

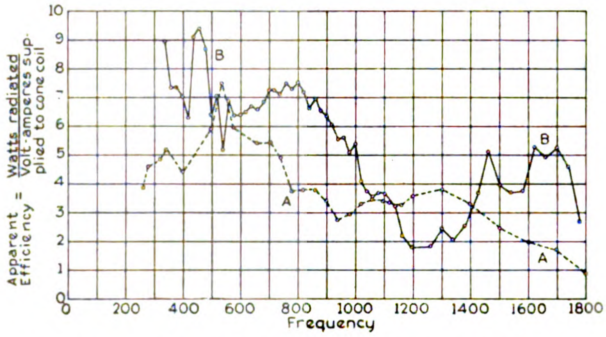


Fig. 6. Curves of Apparent Efficiency of the Loud-speaker Unit

A—With six-inch cone.
B—With twelve-inch cone.

These data have been analyzed further in investigating the conditions within the cone itself. In Fig. 7, the apparent efficiency of the cone itself is plotted. It is the ratio of the radiation resistance to the mechanical impedance of the cone; *i.e.*, it does not include any of the purely electrical constants. These curves show that the radiation resistance comprises the larger portion of the mechanical impedance in the case of the twelve-inch cone; and therefore if the coil and other electrical losses could be diminished, a considerable increase in efficiency could be expected. On the other hand, the six-inch cone appears to have considerable mechanical reactance since the mechanical losses in these cones will be found to be small. Like all other loud speakers, neither the twelve-inch cone nor the six-inch cone can be said to have an ideal characteristic for the reproduction of speech and music. The larger cones cannot be built sufficiently stiff, while the smaller cones do not possess sufficient radiation resistance. This defect in the smaller cones is particularly noticeable in the bass-frequency register. There is, however, a certain crisp naturalness in the reproduction of speech by the six-inch cone which is very pleasing. The twelve-inch cone is somewhat deficient in this regard. In Fig. 8 the radiation resistances of the two cones are plotted for comparison.

A consideration of the physical significance of the equations will reveal how the effective electrical resistance for the various losses in the loud speaker may be segregated. These have been calculated and plotted in Fig. 9. It is seen that the copper resistance of the moving coil constitutes the major portion of the effective resistance of the loud speaker as viewed from the electrical standpoint. The losses in the iron core and copper damping ring are more serious than has been generally supposed, and become equal to the loss in the coil at about 3000 cycles. The mechanical losses in the cone itself are not an appreciable factor except in the vicinity of 3000 cycles where the response is peaked.

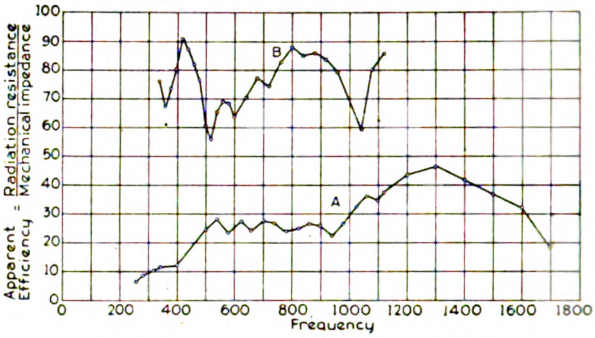


Fig. 7. Curves of Apparent Efficiency of the Cone

A—Six-inch cone.
B—Twelve-inch cone.

The Second Method

The second method of obtaining the efficiency of this type of loud speaker is a more direct one in that the current wave in the cone coil and the displacement of the cone as a function of time were photographed simultaneously on a modified oscillograph.

However, it will be evident that in spite of the directness of the method, the construction of precision apparatus is not as simple as it might appear at first glance. For example, the required speed of the photographic drum to adequately record the current wave and the cone displacement must be great if high-frequency results are contemplated. Furthermore, at the higher frequencies, the cone displacement falls off materially and the oscillographic element used to record the current will be found to have a phase angle between the recorded wave and the current producing it, unless special care has been used in the construction of the oscillograph galvanometer. It will be possible however, to either overcome these defects or to compensate for them over a sufficiently extended frequency range to make this method quite useful in practice.

In order to obtain the displacement curve, a mirror was fastened to a very light shaft which was mounted on jewel bearings. This shaft was rotated by means of a short arm, the free end of which was moved by the cone coil. The weight of the entire moving element (including the mirror) was a very small fraction of that of the cone itself, and therefore affected its motion to only a negligible extent. This system is shown in Fig. 10 from which it may be seen how the light falling on the mirror will record the cone displacement when reflected to a photographic film.

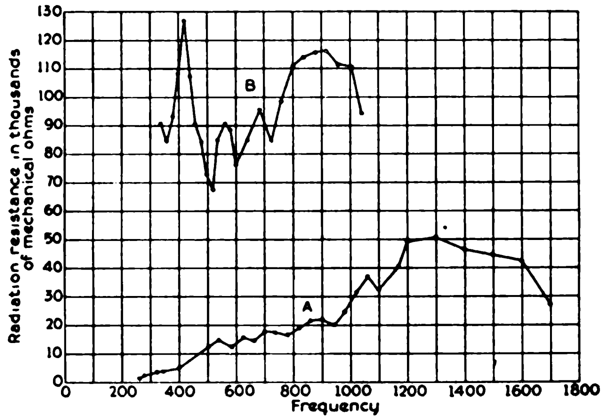


Fig. 8. Radiation-resistance Curves of the Cone

A—Six-inch cone.
B—Twelve-inch cone.

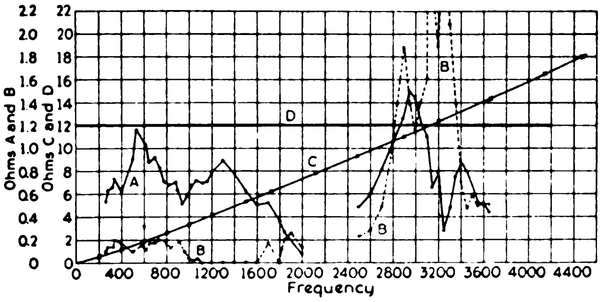


Fig. 9. Segregated Effective Resistances of the Loud-speaker Unit

A—Effective radiation resistance.
B—Effective resistance due to mechanical losses in the cone.
C—Effective resistance due to the losses in the copper ring and in the iron.
D—Effective resistance of the cone coil.

From the curves of the instantaneous values of current in the cone coil and the central displacement, the magnitude of the central force and velocity as well as the phase angle between them can be obtained. Therefore, it is possible to calculate the mechanical impedance of the cone when operating either in air or in a partial vacuum. If F_a and V_a are respectively the central force and velocity in air, and F_v and V_v are similar quantities in a partial vacuum, then in mechanical units:

$$(r_a+r_c)+j\,(x_a+x_c)=Z_m=\frac{F_a}{V_a} \tag{8a}$$

$$r_c+jx_c=Z_c=\frac{F_v}{V_v} \tag{8b}$$

The efficiency is very easily obtained from these relationships. To determine the apparent efficiency, it is necessary first to know the voltage e across the cone coil with the cone operating in free air. Since the velocity in centimeters per second and the current i in abamperes must be known to find the mechanical impedance in free air, it is quite simple to use the following relation for apparent efficiency:

$$\eta=\frac{r_a V_a^2}{10^8\,ei} \tag{9}$$

where e is measured in practical units.

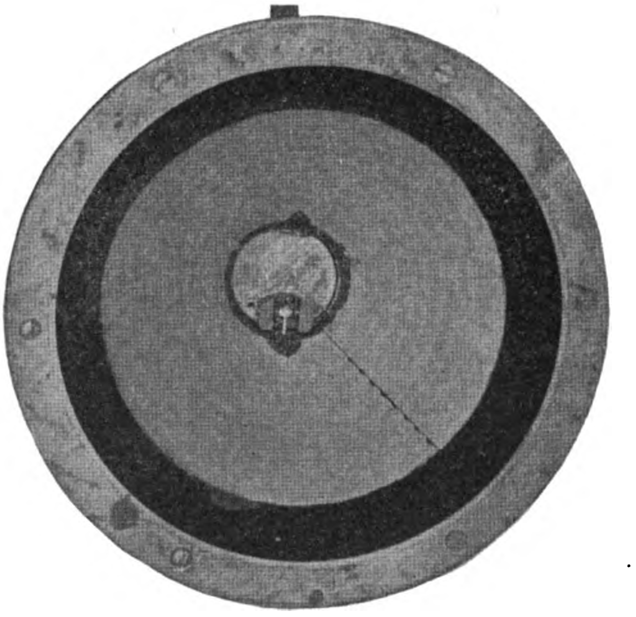


Fig. 10. The Mounting of the Vibrator Mirror Used in Making Efficiency Tests by the Second Method Described

If the effective electrical impedance of the cone coil is known under these conditions, the power-factor ($\cos\alpha$) may be obtained. Therefore the actual efficiency is:

$$\eta=\frac{r_a\,V_a^2}{10^8\,ei\cos\alpha} \tag{10}$$

This method is relatively simple to use and although not quite so accurate as the first method, it does not require the extreme care necessary in that method. It is sufficiently accurate for general developmental work, however, even though it probably cannot be used over a frequency range as wide as that of the preceding method.

Comparison

A comparison of these two methods in measuring the radiation resistance in electrical units is shown by Table I, in which the agreement between the two methods is quite satisfactory. The range of frequencies compared was limited at the high end by the safe speed of the photographic equipment of the oscillograph.

Efficiency of the Cone-driven Horn

It was felt that the cone might be more efficiently loaded by the application of a horn and, in consequence, an exponential horn having a cut-off frequency of about 60 cycles and a mouth 80 in. in diameter was built. This horn is shown in Figs. 11 and 12.

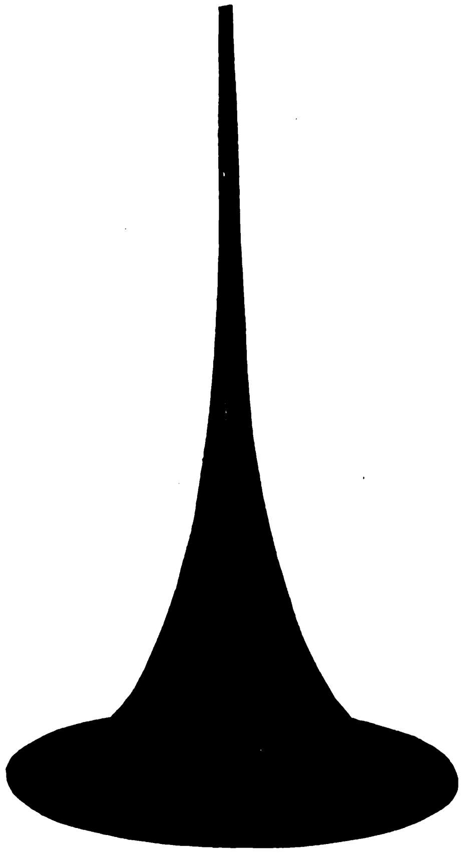


Fig. 11. Assembly of a Loud-speaker Horn Constructed for the Purpose of Test

The design was such that it was possible to use various lengths of horn with the same mouth piece.

Tests indicated that a horn having a throat about two inches in diameter was the most satisfactory for use with a six-inch cone driver. The longer lengths of horn, which had smaller throats, showed lower outputs due to increased air friction losses. The sound pressure curves showed a marked loss of high-frequency response in these cases. The short horns with throats about six inches in diameter had increased high-frequency response since the cone was acting as if it were in a large baffle at these frequencies. The middle register showed a depression, however. The efficiency of the horn with a six-inch throat was not materially different from that of the horn with a two-inch throat. In comparison with the same cone operating on a large baffle, it was found that the efficiency of the plain cone and the cone-driven horn were practically equal except at the lower frequencies. This is shown in Fig. 13. It was found, however, that the performance of the cone on a baffle was noticeably superior from a "fidelity" standpoint. The horn gave more perfect bass response but was deficient either in the middle register or the high-frequency end of the characteristic, depending on whether the six or the two-inch throat was used.

TABLE I

RADIATION RESISTANCE IN ELECTRICAL UNITS

Frequency	By Bridge Method	Calculated from Mechanical Measurements
500	0.84	0.86
520	1.04	0.85
560	0.92	1.04
580	0.87	0.92
620	0.84	0.97
680	0.84	0.63
740	0.75	0.77

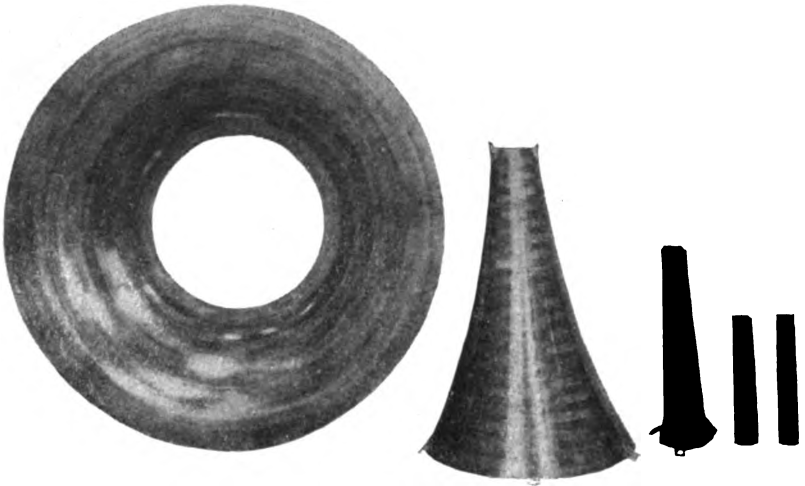


Fig. 12. The Component Parts of the Test Horn Shown in Fig. 11

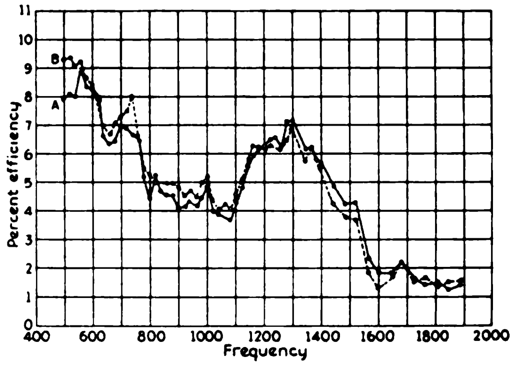


Fig. 13. Comparison of Efficiency of the Loud-speaker Unit with a Baffle and with an Exponential Horn

A—Six-inch cone on large baffle.
B—Same cone driving an exponential horn with a six-inch throat.

In this work, the author was fortunate enough to have the interest of W. R. G. Baker, the advice and criticism of E. W. Kellogg, and the assistance of A. R. Barfield in the construction and manipulation of the apparatus involved. He therefore wishes to acknowledge the assistance which they rendered so generously.

Thyratron Control Equipment for High-speed Resistance Welding

By R. C. GRIFFITH
Research Laboratory, General Electric Company

SUCCESS in the operation of spot welding depends largely upon the control of the current flow in the primary circuit of the welding transformer. In the type of resistance welding known as interrupted line welding, the service requirements of the control device are particularly severe. For this reason application has been made of the Thyratron tube as the make-and-break device in the control equipment.

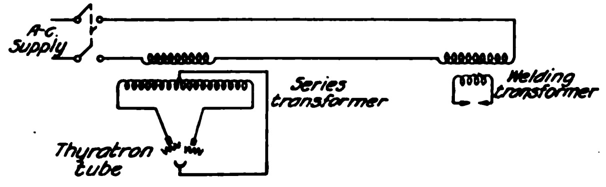


Fig. 1. Diagram of Circuit for Applying Thyratron Tube Control to Spot Welding Equipment

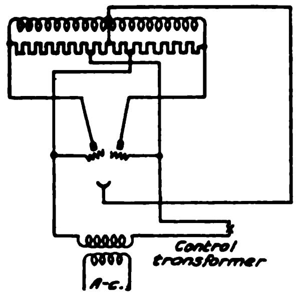


Fig. 2. The Control Circuit. Control contacts may be operated automatically or by hand

As shown in Fig. 1, the equipment consists of a transformer, the primary of which is in series with the welding transformer primary, and a Thyratron tube connected in the secondary. Inasmuch as a tube is limited by the current it can carry, the secondary voltage is made several times greater than the primary. Thus if the secondary voltage to neutral is 1100 with a line voltage of 440 and a primary current of 150 amp., the secondary current is $\frac{440}{1100} \times 150 = 60$ amp. r.m.s., or 55 amp. average during operation. The transformer is designed for r.m.s. or heating current, while the tube heating is determined by average current.

The operation depends on the fact that when the two transformer secondaries are open-circuited the only current flowing is that required for excitation, but when the secondaries of the transformers are short-circuited the full line voltage, less a drop across the primary of the series transformer necessary to take care of its excitation and losses, is applied to the welding transformer. With the ordinary transformer design this loss will be about five per cent. Therefore, 95 per cent of the line voltage will be applied to the welding transformer, which experience shows is satisfactory. However, the line voltage may be raised five per cent if desired and the normal voltage will be applied to the welding transformer.

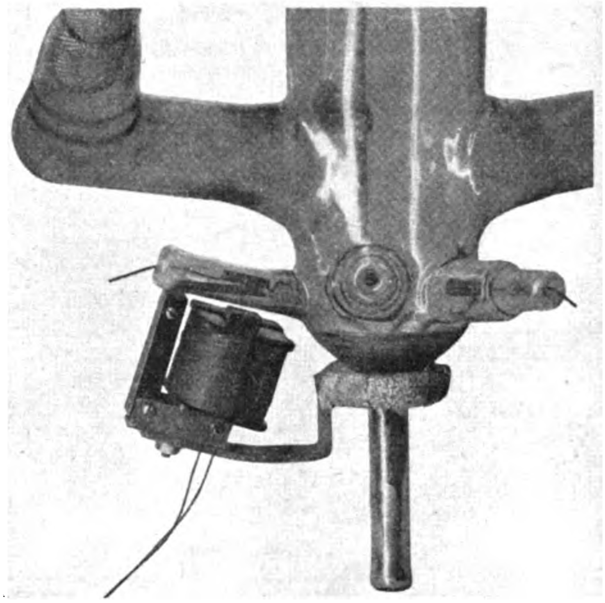


Fig. 3. Electromagnetic Starter Applied to a 20-amp. Thyratron Tube

The control circuit with the tube is shown in Fig. 2. With the control contact open both grids are negative when their respective anodes are positive, thus preventing the flow of anode current; but when the control contact is closed a current is sent through the resistor, which reverses the grid polarity and permits the flow of current.

Starting the tube in operation is accomplished by a small electromagnet attached to the tube as shown in Fig. 3. A light molybdenum spring is sealed into the glass with its tip a short distance above the mercury surface. A small strip of iron is hung to the under side and is pulled down by the electromagnet into the mercury and then released. The spark thus made permits the holding arcs to form, opening a relay and stopping the wire from dipping into the mercury. The starting time is about one-quarter of a second with the tube at ordinary temperatures. The tube has been started when the ambient temperature was five degrees below zero (F.) and also after the tube had been carrying 100 amp. for some time. Tests indicate that, in spite of its lightness and the severity of the requirements, the spring will continue to function throughout the period of usefulness of the tube.

An illustration will indicate what is required of a tube in such an application. A welding machine has a transformer whose primary current, when welding, is 225 amp. The supply voltage is 440. The control contacts close for one-sixth of the time on each revolution of the cam which rotates 60 times per minute. A stop-watch check shows that about one-half of the time is required for changing the work in the machine, so that the ratio of welding time to total time is $\frac{1}{6} \times \frac{1}{2} = \frac{1}{12}$. The heating or r.m.s. value of the current is then $\frac{225}{\sqrt{12}} = 65$ amp. Therefore, the primary of the series transformer has a capacity of $\frac{65 \times 440}{1000} = 28.6$ kv-a. Since each half of the secondary will carry the current for half the time and if each has n times the primary turns the secondary current $\frac{65}{n\sqrt{2}} = \frac{46}{n}$ amp. r.m.s. Assume the secondary voltage to neutral be 1100. Then $n = \frac{1100}{440} = 2.5$ and the current carried by the secondary is $\frac{46}{2.5} = 18.4$ amp. r.m.s. The equivalent capacity of the transformer is then $\frac{2200 \times 18.4 + 440 \times 65}{2 \times 1000} = 34.5$ kv-a.

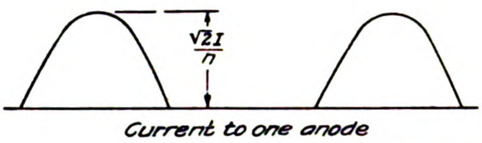


Fig. 4. Wave Form of Current Supplied by Tube

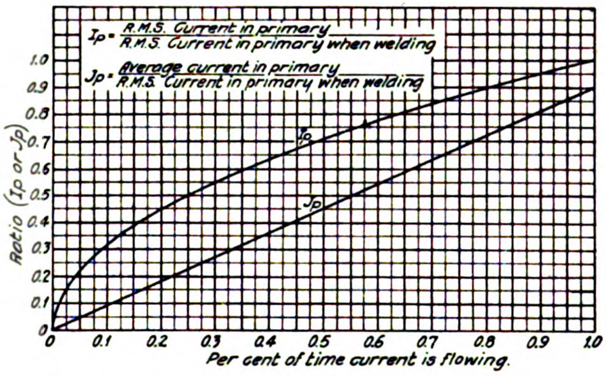


Fig. 5. Current Ratios as Influenced by Duration of Flow

The tube rating is based upon average current, and Fig. 4 shows that each anode will carry an average current of $0.318 \times \sqrt{2} \times \frac{225}{2.5} = 40.5$ amp. where 0.318 is the ratio of average to peak value over a full cycle or 360 electrical degrees. Since there are two anodes the total current is 81 amp. average while current is flowing.

Since the anodes have a relatively small heat capacity the question arises: Over how long a period can the current be averaged? Equipments are in service which have a cycle of 20 seconds welding, in which period about 20 spots are made, and 20 seconds to change the work. We will further assume that the previous requirements are not exceeded in this case which gives an average current of $\frac{81}{12} = 6.8$ amp.

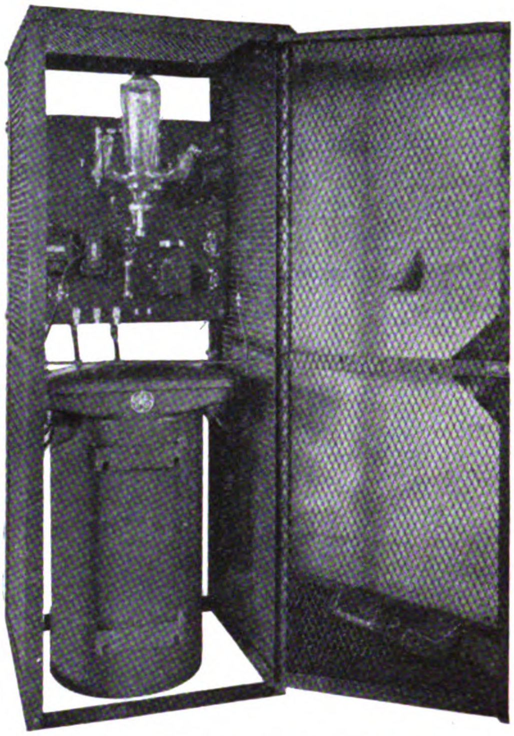


Fig. 6. An Early Form of Panel for Thyratron Control of Spot Welding Equipment

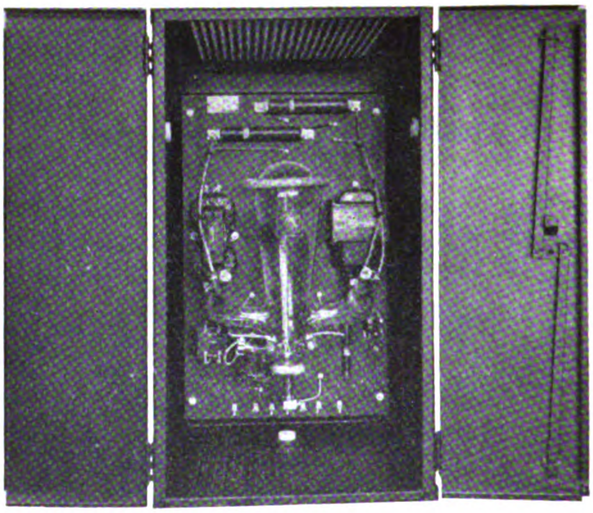


Fig. 7. Thyratron Tube Control Equipment of Recent Design for Spot Welding Application

Now a two-anode tube must be selected which will carry an average current of 6.8 amp. and permit peaks of $\frac{\sqrt{2}\times 225}{2.5} = 127$ amp. The mercury-pool type is ideally adapted to do this by making the seals large enough to carry the peak currents. In a typical installation a 45-amp. tube ran for three months with peaks of 220 amp. and was in excellent condition at the end of this period.

Fig. 5 shows the ratio of r.m.s. current in the primary circuit to the r.m.s. current drawn while welding, and also the ratio of average current in the primary circuit to r.m.s. current drawn while welding, both plotted against the percentage of time current is flowing. Thus, following the method outlined for a specific problem it may be shown that, in general, the average current in the tube will be

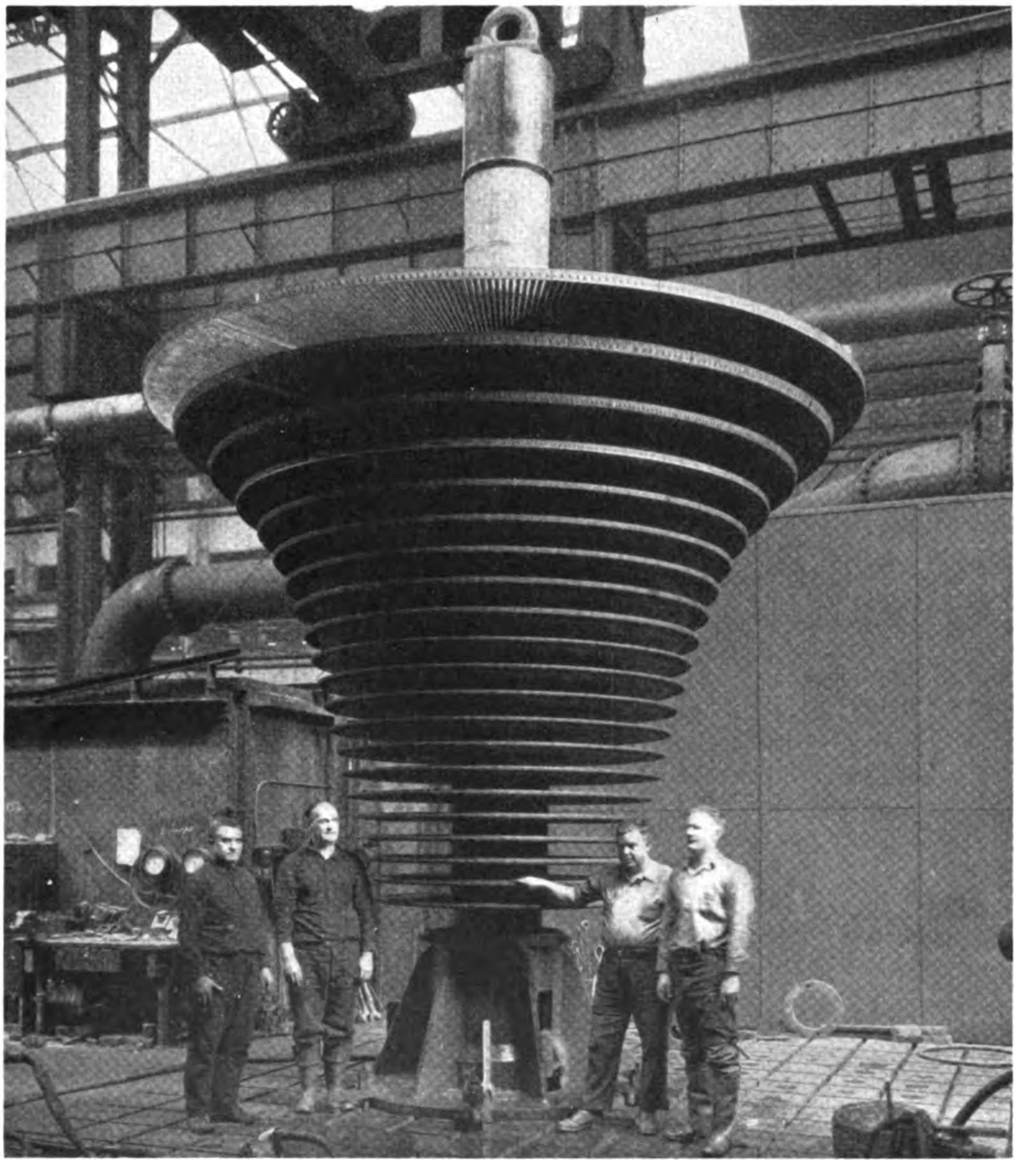
$$\frac{0.9 \times I \times a}{n}$$

where I = r.m.s. value of primary current while welding

a = percentage of time current is flowing

$n = \frac{\text{secondary volts to neutral}}{\text{line volts}}$

In Fig. 6 is shown an early panel built for this service and Fig. 7 shows one of later design. Both of these have 45-amp. tubes. The second has the enclosure around the panel only, since it is found more convenient to handle and takes up less space.



Rotor Assembly of 50,000-kw. 21-stage Steam Turbine

Illuminated Ice at Lake Placid Club, N. Y.

Special Lighting for Winter Sports—Tests for Spectacular and Unique Installation—Devices Required for Waterproofing and Flashing—Installations and Color Effects

By L. C. PORTER and W. A. STEIGER
Engineering Department, Edison Lamp Works
General Electric Company

LAKE PLACID, in the heart of the Adirondacks, furnishes superb facilities for every form of winter and summer sport. As a place for providing clean, healthy sport, the Club is unique in many ways; and children are permitted to romp and make merry in its spacious halls.

The winter of 1929-30 marked the twenty-fifth anniversary of the opening of the Club for winter sports. On this occasion the lighting installed for appropriately illuminating the grounds and buildings (which now embrace in extent and value figures of 10,600 acres and $4,000,000 respectively) was exceptionally noteworthy; it is the purpose of this article to portray, in so far as simple words and pictures will permit, the nature of the illumination and to describe the means by which the various effects were produced.

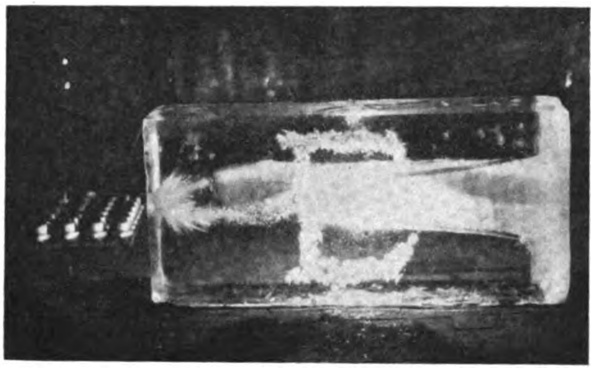


Fig. 1. Illuminated Initial Formed on a Block of Artificial Ice by Hammer Blows

In preparation for the winter's festivities, the Club sought to have designed and installed some sort of lighting that would be different from anything ever done before. It thus became the writers' task to create a new mode of lighting appropriate for winter carnivals.

Since ice and snow form the basis of the outdoor sports, and also provide Nature's beautiful winter clothing, it was decided to use these in connection with the lighting. The most obvious manner was to floodlight some of the magnificent pines and hemlocks when they were covered with ice and snow. Colored floodlight projectors were provided, whereby the pure white snow was turned blood red, then green, blue, and yellow, and other colors by various combinations, producing veritable pictures painted with light. The effects proved exceedingly beautiful. That, however, was not particularly new nor original. It had been done many times in connection with Christmas lighting.

Searching for something original, the thought occurred to the writers that if colored lamps could be frozen into the ice of the skating rink, some very novel and pretty designs could be worked out. No record could be found of having done this before, and no data were available as to what would happen to lamp bulbs when frozen solidly in about six inches of ice. This was tried out during the preceding summer by freezing lamps into artificial ice. Somewhat to the surprise, and much to the delight of the designers, it was discovered that very few of the bulbs broke, which indicated that the skating rink idea was practical. It also appeared that some gorgeous and unusual effects might be obtained by placing colored lamps in a great pile of broken ice; this was tried out also.

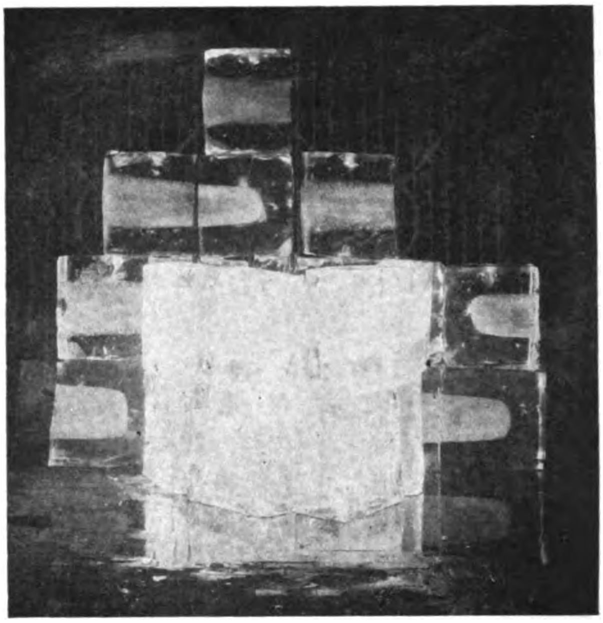


Fig. 2. Luminous Ice Blocks. The light is produced by bulbs suspended behind the ice

Some very interesting things were learned during the developments. It was found, for example, that a concentrated beam of light could be projected through many blocks of ice (clear artificial ice) with very much less diffusion than through a corresponding amount of water. The light was hardly visible as it passed through the clear ice, but where it hit snow-ice, cracks, crystals, or the corner of the blocks, it was broken up into prismatic colors, producing some very beautiful effects. Very attractive designs, initials, etc. could be produced by hitting the surface of the clear ice with a hammer (Fig. 1). The star cracks thus formed picked up the light and caused the design to glow in much the same manner as the signs etched into pieces of plate glass and lighted from the edge of the plate. For these effects the lamps could be either suspended behind the block of ice, or frozen into the center. It is impossible to show by a picture the beautiful irridescence obtained in the ice.

Tests were made on various types of artificial ice. It was found that the manufacturers can produce clear ice or snowy ice. They can cause the bubbly core to be in the center of the block, or near the edge. The crystals can be made large or small. All of these things have some effect on the lighting.

If whole cakes were used, and colored lamps placed behind them, the best effects were found in cakes with snowy cores, as shown in Fig. 2. The most beautiful effects, however, were obtained by breaking up the ice into jagged pieces from six inches to one foot thick, and simply piling them over the lamps. The more irregular the ice, the better the pieces acted—much like prisms breaking up the light and causing very beautiful combinations of color.

The next variation tried was to add changes to the color. To do this flasher buttons were put in the lamp sockets. The slow-speed buttons were found more pleasing than the quick-flashing ones. The result was exceedingly spectacular. A pile of broken ice having flashing colored lamps under it appeared like a scintillating opal.

The most pleasing effects were obtained by having some of the lamps (about every fourth lamp) burn steadily; using different colors seemed to cause the changing colors to blend more softly and lessen the spotty, jumpy effect that is in evidence where all of the lamps were flashing.

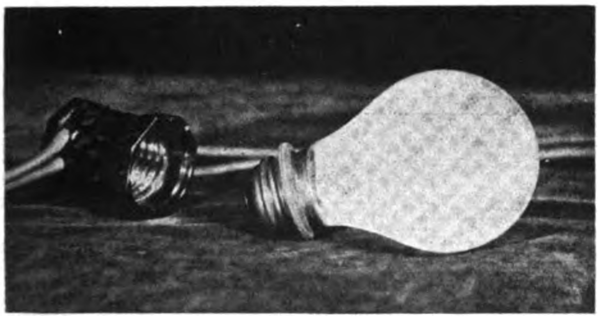


Fig. 3. A Bulb and Socket for Illuminating Ice. Note the special insulating ring for keeping the interior dry

Tests were also made with lamps of various wattages. Inside-colored, outside-coated, and natural glass lamps were used. The higher transmission of the natural glass lamps makes them desirable for this work; and 25-watt natural glass lamps proved as effective as 40-watt coated lamps. Alternate red, blue, green, amber or yellow lamps gave the best combinations. For yellow or amber, 10-watt lamps were found the best particularly for those that burned steadily, as the yellow light has a tendency to wash out the other colors.

Where an ice pile of this sort is desired for temporary use, such as one night at a garden party, or a carnival in summer, or for Christmas week, it can be very easily constructed by the use of a single 100-ft. decorative streamer with lamp sockets spaced two feet apart.

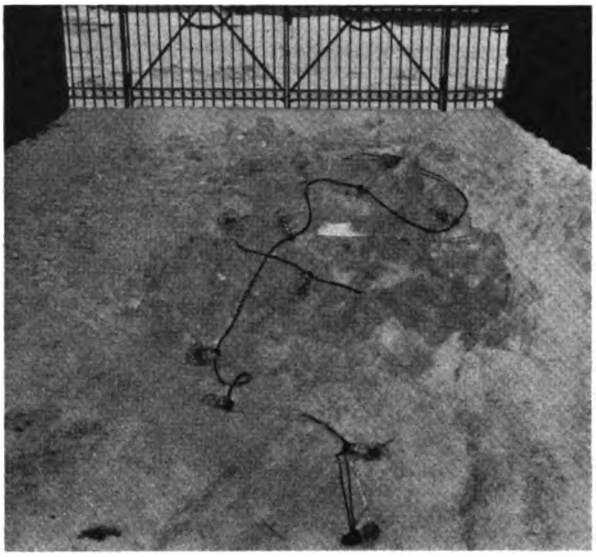


Fig. 4. The Test Pile of Ice at Harrison (N. J.) When About Three-quarters Complete, Showing Method of Building-in the Lamps

The flasher buttons are put in the sockets, and the lamps equipped with insulator ring washers (Fig. 3) to keep water from running into the socket and the lamp base. The lamps are screwed in place, and lamp guards attached to the sockets to protect the lamps from breakage as the ice is piled on.

Two thousand pounds of artificial ice cut up into pieces from six inches to one foot thick will make a pile about 10 feet in diameter at the base, and four or five feet high.

The streamer with lamps and guards in place is simply coiled around on top of the ice as the pile is built up. The lamps should be kept about one foot in from the outside of the pile. Figs. 4 and 5 show stages in the process of constructing such a pyramid.

TABLE I

Date	Weather	TEMPERATURE, DEG. F.	
		Maximum	Minimum
Dec. 4, 1929........	Clear	28	18
Dec. 5, 1929........	Clear	26	16
Dec. 6, 1929........	Cloudy	54	35
Dec. 7, 1929........	Foggy	58	38
Dec. 8, 1929........	Clear	53	40
Dec. 9, 1929........	Clear	38	30

The length of time that such a pile will last depends, of course, upon the weather: the amount of sunshine, wind, etc. Fig. 6 shows the decrease of such a pile built in the yard at Harrison (N. J.). The weather conditions during the period of test are given in Table I.

The life of the pile can be extended by covering it with blankets during the day. This was not done in the present instance, however.

As the ice disappeared by melting and sublimation, the sockets and wires gradually came to the surface. More ice could be put over the lamps, but sooner or later they sink into a heap on the ground.

If it is wished to maintain the pyramid for a considerable time, the lamps must be supported. This was the case at the Lake Placid Club, where it was desired to keep the ice pyramid during the entire winter season. To do so, a wooden tree was constructed, the eight bottom arms of this tree being each six feet long. Two feet above these were eight more arms each four feet long, and two feet above those another set of eight, each two feet long. These arms were made of two by four-inch pieces and attached to a four-inch center post eight feet high. A total of 60 weatherproof lamp sockets were located two feet apart along the various arms.

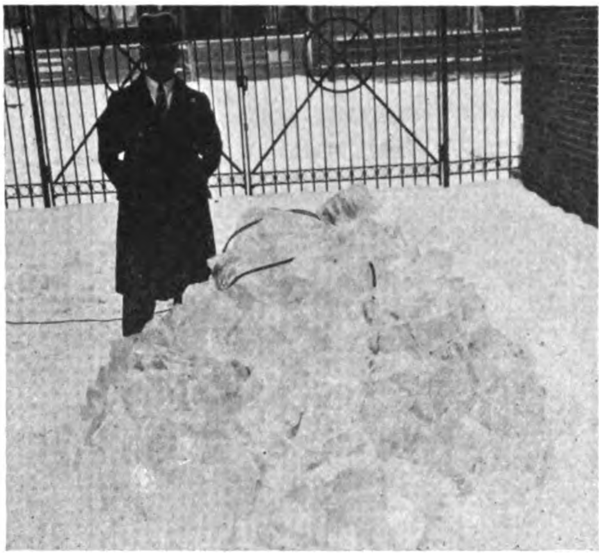


Fig. 5. The Complete Test Pile, Six Feet in Diameter and Four Feet High, with Lamps Completely Imbedded in Ice. The lamps burned six hours daily

In selecting the lamp sockets care must be used to secure a type which has a deep enough base shell to allow for the thickness of the flasher button, and still have threads enough left to hold the lamp base. If no such sockets are readily available, socket extensions can be used in the short-shell weatherproof socket and the flasher button put in the socket part of the extension, which has a long shell. In that case it is desirable to shellac or varnish the paper shell of the extension to waterproof it. The lamp and extension base should each be equipped with a special rubber insulating ring.

The four-foot arms of the lamp tree were staggered between the six-foot and the two-foot arms so as not to have the lamps in all three layers come directly above one another.

Fig. 7 shows the lamp tree under construction. The arms were held to the center post by brackets, and guyed with wire from the top.

After this tree was in place on the Garth (the great open lawn between the two main Club buildings, Agora and Forest), ice was piled on. Twenty tons of ice were cut from Mirror Lake and broken up into pieces of suitable size, which were piled around and over the lamp tree, completely covering it. This made a pile about 20 feet in diameter at the base, and 10 feet high. When the lamp tree and lamps were completely covered (Fig. 8) nothing was left showing but the light shining through the ice.

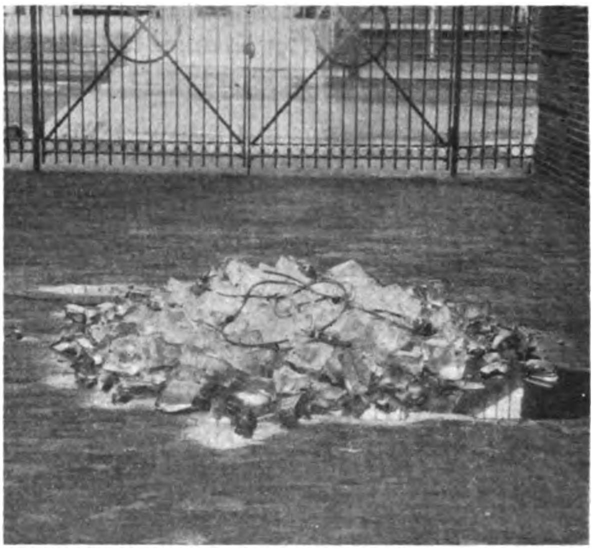


Fig. 6. The State of the Test Pile Four Days Later, Having Been Exposed to Temperatures as High as 58 deg. F., and to the Sun for Two Hours Per Day

The result was marvelous; with light constantly changing and producing not only pure, deep, rich reds, blues, and greens, but all the delicate shades and tones of the various combinations of these colors. Thus the ice pile proved a great success: a new mode of artificial lighting; something that had never been done before in the world. This great colored pile that seemed almost alive could be seen from the village of Lake Placid, all the way across beautiful Mirror Lake.

The other novel form of ice lighting consisted of a great star formed by some 174 lamps frozen directly into the ice of the skating rink. The star itself was made of fabricated streamers having sockets spaced six inches apart. This five-pointed star was laid out on the ground before the skating rink was flooded (Fig. 9). Then one hundred and forty 10-watt yellow-bulb lamps were screwed into the sockets outlining the star and thirty-four 25-watt red and green lamps were used to form the Club's initials in the center of the star.

After each lamp was screwed in, the socket and lamp base were immersed in molten paraffin, then held upright until the wax set, thus completely sealing the lamp in and insulating it from the water in which it would have to soak during the process of flooding and freezing. The lamps were held in position by driving staples over the wires into the ground.

The first night the rink was flooded to a depth of about one inch, thus bringing the water only part way up on the bulbs. The temperature that night went to twenty degrees below zero, resulting in a quick, hard freeze which broke several of the lamps. These were dug out of the ice the next day, and replaced by new ones.

The flooding and freezing process, adding about an inch of ice at a time, was continued until there was about an inch of ice on top of the lamp bulbs. A fence was placed around the star during the freezing process to protect it from curious or thoughtless skaters. When the job was completed (see frontispiece), the fence was removed.

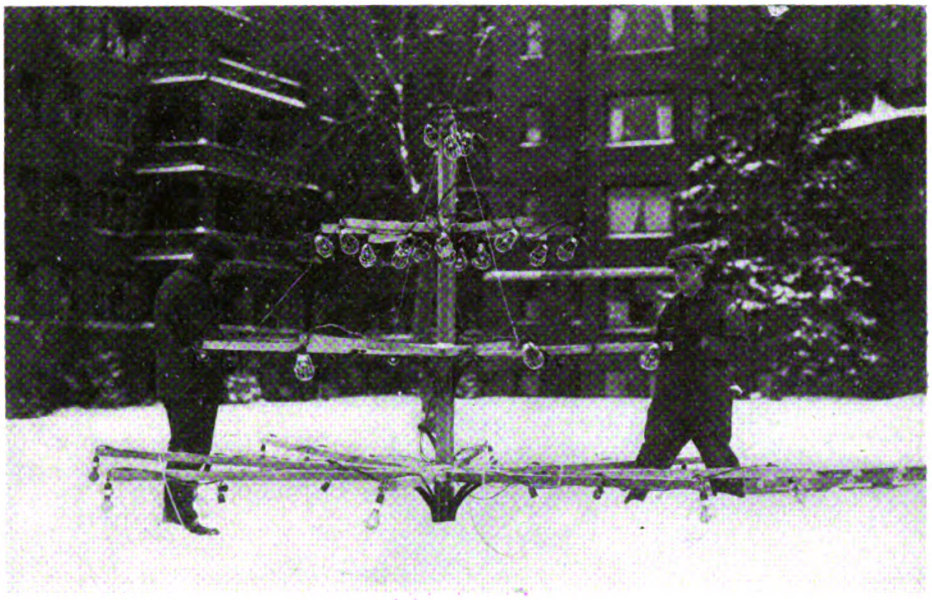


Fig. 7. Framework for Supporting Lamps in the Illuminated Pile of Ice at Lake Placid Club

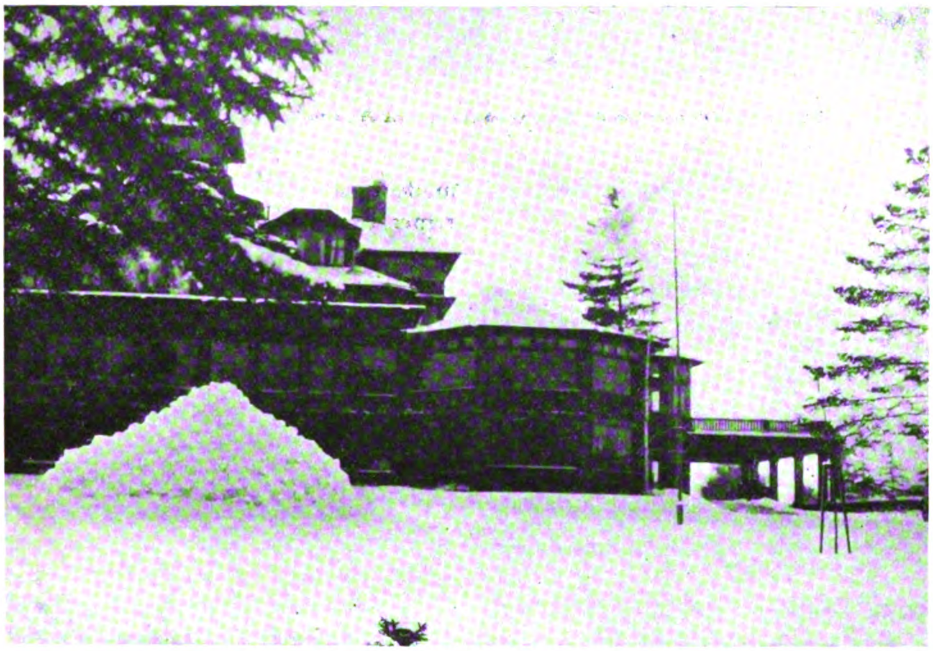


Fig. 8. The Completed Pile by the Clubhouse

Very little lamp breakage occurred after the lamps were completely covered. It is probable that the unequal pressure caused by the unequal flooding was responsible for the breakage that did occur. It might eliminate this trouble if the lamps were left burning during the freezing periods, at least until the bulbs are entirely covered with water.

This star was very effective, and caused no small amount of curiosity as to how it was done. Some hazarded the guess that the ice itself was colored. Others thought the design was projected into the ice from a hidden stereopticon. Some of the youngsters, however, were not to be fooled. One or two of them were found thoughtlessly digging down into the ice with the toe of their skates to see how far down the lights were.

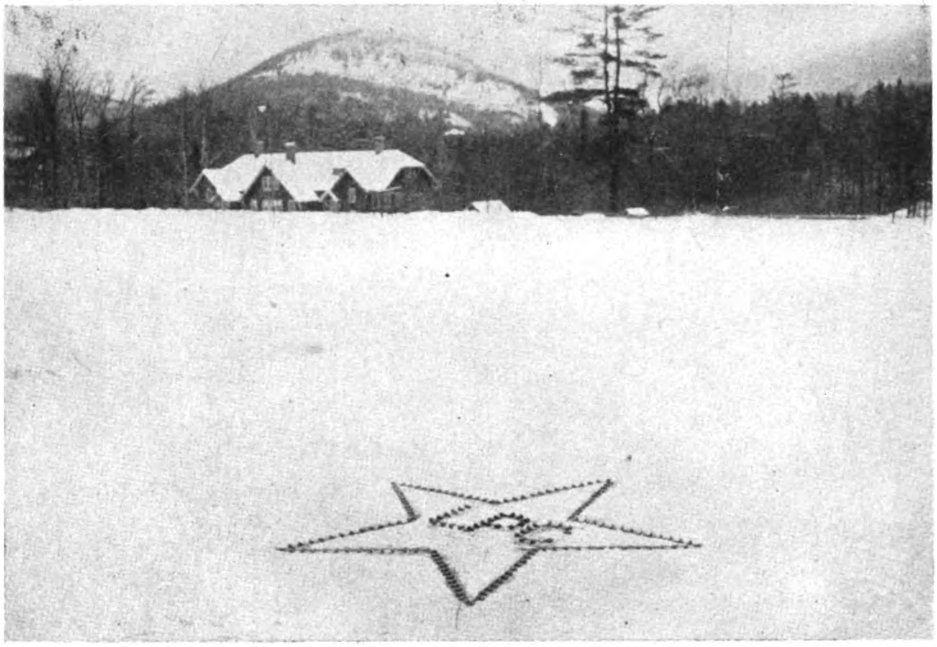


Fig. 9. Star Outlined in Bulbs on the Skating Rink Prior to Freezing Into the Ice

There was considerable speculation and some fear that the heat of the lamps would soften the surface of the ice, or cause holes in it. While the display lasted, however, no trouble was experienced of that sort in spite of the fact that some 2250 watts of energy were being dissipated by the lamps in the ice. The bulbs seemed to melt a little of the ice around them, but this did not extend through to the skating surface. This type of decorative lighting lends itself to all sorts of places, not only for outdoor skating rinks, but indoor as well.

Perhaps the most colorful ice carnival in the country was held on this rink the night before New Year's Eve. The rink itself was outlined with colored electric lamps. Below these were strings of Japanese lanterns. On the far side of the rink was a wire fence to which had been fastened hundreds of glass tumblers, each containing a light. Behind these was a great bank of pure white snow. As a background for the whole, there was released about 100 hp. in steam from the power house, and colored floodlights were played on the steam. Two red, two blue, two green, and one amber projector containing 500-watt lamps were used. The sources of the steam and the light were below the snow bank. As the ever-changing colored steam came idly drifting, apparently out of the snow bank, it made a gorgeous and fascinating display. Only those who have seen such a steam beacon(1) can appreciate its fascinating beauty.

Several hundred skaters were on the ice in costume, and each carried a flaming torch. The whole scene made a picture of color and motion which will long be remembered by those who saw it.

One other ice lighting effect was also used at the Club. That consisted of a colored streamer with flashing colored lamps spaced every foot along it, placed in such a position that the long row of great grotesque icicles hanging down from the roof would form around the lamps. Here, too, the effect was novel and most attractive. The icicles seemed to pick up the light and carry it down through them to their very tips. These long, jagged spears, changing continuously in color and sparkling at the same time, were indeed a beautiful sight.

In conclusion, appreciation is expressed for the close coöperation and assistance given by the Club's electrical engineer, Mr. W. H. Fraser, and his workmen. On them fell the details and actual installation work. They showed no small amount of ingenuity and ability in overcoming some of the trials that always arise in accomplishing something that has never been done before.

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(1) "Colored Luminous Steam," by L. C. Porter, G. F. Prideaux, and W. H. Steiger, GENERAL ELECTRIC REVIEW, May, 1929, pp. 284-287.

A Power-factor Treatment of Non-sinusoidal Current Waves

Non-sinusoidal Waves the Resultant of Two or More Sinusoidal Waves with or without a Direct-current Component—Mathematical and Graphical Analysis of Sinusoidal and Non-sinusoidal Waves Combined—Illustrated by Vector Model

By F. B. VOGDES
Research Laboratory, General Electric Company

THE sine wave of current which prevails throughout the field of rotating machinery is decidedly uncommon in devices in which rectification or any form of conduction through gases takes place. Specific cases are readily called to mind: *e.g.*, the mercury arc, tungar, and copper-oxide battery chargers, the General Electric Vapor Lamp (formerly known as the Cooper-Hewitt lamp) and lamps designed for the production of ultra-violet light; all have components of higher than fundamental frequency in their input current wave. The first question which arises in these days of widespread radio interest is that of telephone and radio interference. A few devices have been found to be such bad offenders in this respect that their use has been practically discontinued, but the remainder present only the "sparking connection" hazard which they share in common with all electrical appliances. This means that the components of their currents are of such magnitude and frequency as to cause no difficulty.

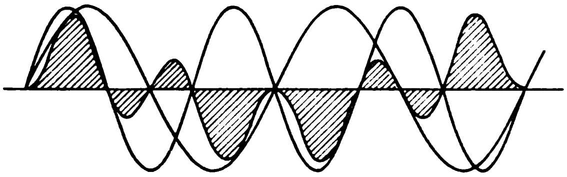


Fig. 1. Instantaneous Product of Two Sine Waves of Different Harmonic Frequencies Will Average Zero Over a Complete Cycle

When the power-factor of these devices is discussed they are frequently the victims of unjust, although entirely unintentional, discrimination. This is due to the habits of thought of the average engineer who has so many problems in various fields clamoring for attention that he thinks of power-factor as the "cosine of the angle" until shown that this viewpoint is inadequate.

Going back to first principles, a current of non-sinusoidal form can be shown mathematically to be exactly the same as a number of currents of sinusoidal shape expressed in the form of a double series. That is:

$$i = a_1 \sin wt + a_2 \sin 2\,wt + a_3 \sin 3\,wt + a_4 \sin 4\,wt + \cdots\cdots + a_n \sin n\,wt + b_1 \cos wt + b_2 \cos 2\,wt + b_3 \cos 3\,wt + \cdots\cdots + b_n \cos n\,wt$$

In the most general case there is also a component representing a direct current. It is apparent that if the values of the different coefficients in the series were determined, the knowledge would be of little practical value. The current must be described in such a way that the figures have immediate significance without the traversing of extensive algebraic jungles. Examination of the mathematical value of the series shows that this is readily accomplished when the mutual losses due to the different currents are seen to be zero.

The mutual loss resulting from two currents is a logical and useful, though not very common, conception. Going back to the college problems of the street cars, which always seem to find a new way of distributing themselves along the line, let there be two cars only a few hundred feet apart and several miles distant from the single source of power. One car draws a current $i_1 = 100$ amp. and the other a current $i_2 = 150$ amp. and the total resistance of the trolley and rails is ½ ohm. The total loss in watts is $ri^2 = \frac{1}{2}(100+150)^2$ and this may be quickly calculated as $\frac{1}{2}\times 250^2 = 31{,}250$ or more leisurely as $\frac{1}{2}(100^2+2\times 100\times 150+150^2)$. In the second case there is a loss due to the first car of $i_1{}^2r = \frac{1}{2}\times 100^2 = 5000$ watts, a loss due to the second car of $i_2{}^2r = \frac{1}{2}\times 150^2 = 11{,}250$ watts; and a further mutual loss due to the fact that they both run at the same time which is equal to $2r\,i_1\,i_2 = 2\times\frac{1}{2}\times 100\times 150 = 15{,}000$ watts.

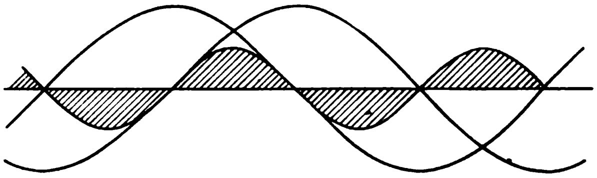


Fig. 2. Instantaneous Product of Two Sine Waves Displaced 90 deg. in Phase Will Average Zero Over a Complete Cycle

Now sinusoidal current waves which are of different frequencies have an instantaneous mutual loss which is sometimes positive and sometimes negative but which always adds up to zero over a complete cycle if the two frequencies are both whole multiples of a basic fundamental frequency (Fig. 1). This very materially simplifies the calculation of the heating value of the long series of terms. The heating value of each term can be calculated separately and the heating value of the whole is the sum of these individual values and no more. The "a" terms and the "b" terms represent waves of the same frequency separated 90 deg. in phase and follow the same law (Fig. 2).

If, now, a device with a non-sinusoidal wave form is to run in parallel with, let us say, an induction motor, what is the minimum number of factors that must be known in order to give a comprehensive description of the resultant load? Since the motor draws a sine wave of current there will be no mutual loss between its current and the higher frequency components of the other device which will be called "the lamp." There will, however, be mutual losses between the two fundamental-frequency components of motor and lamp. Listing the components in parallel columns there results:

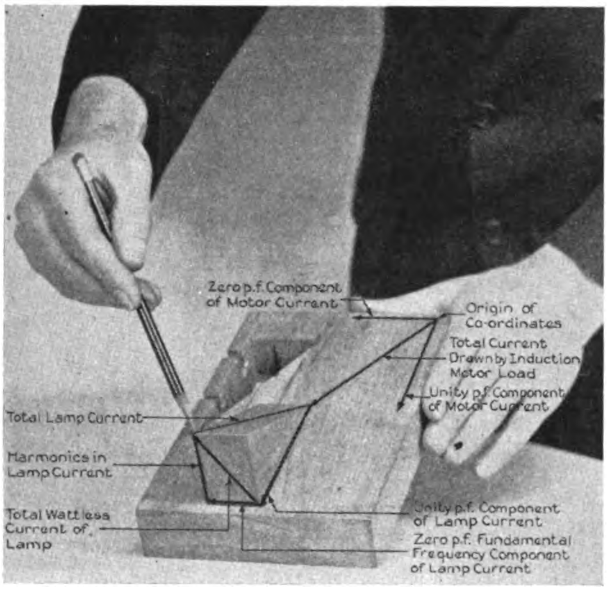

Zero p.f. Component of Motor Current
Origin of Co-ordinates
Total Current Drawn by Induction Motor Load
Unity p.f. Component of Motor Current
Total Lamp Current
Harmonics in Lamp Current
Total Wattless Current of Lamp
Unity p.f. Component of Lamp Current
Zero p.f. Fundamental Frequency Component of Lamp Current

Fig. 3. Model of Three-dimensional Vector Diagram Made to Illustrate the Addition of a Load Having Harmonic Currents to One That Has Not. In this model, the resultant current is represented by the straight-line air distance between the origin of the coördinates and the point of the pencil

Motor	Lamp
Unity power-factor fundamental-frequency component.	Unity power-factor fundamental-frequency component.
Zero power-factor fundamental-frequency component.	Zero power-factor fundamental-frequency component.
	Harmonic-frequency components (lumped as one to give their total heating value).

Each component will give its individual heating effect but only two mutual effects exist. These are:

(1). Mutual losses due to unity power-factor fundamental-frequency components.

(2). Mutual losses due to zero power-factor fundamental-frequency components.

The next step is to arrange the results in graphic form. Vectors are "quantities having magnitude and direction" and common practice is to represent currents by vectors in one plane which rotate at synchronous speed and have a projection on a fixed axis equal to the instantaneous value of the currents portrayed. Since the harmonics have different "synchronous speeds" than the fundamental, it would appear that vectors are unsuitable for the present problem. Vectors have, however, a very useful property in that three may be drawn mutually at right angles in three dimensional space and the square of the vector sum will be equal to the sum of the squares. Since the problem involves currents which have been reduced in number to only three kinds, advantage can be taken of this fact. The stipulation must be made, however, that the angles between the vectors may have no meaning whatever or else a very limited one.

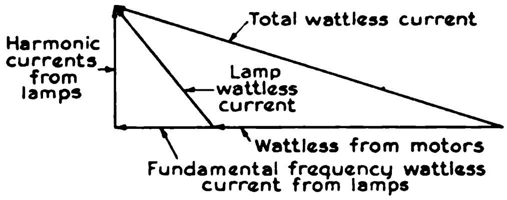

Total wattless current
Harmonic currents from lamps
Lamp wattless current
Wattless from motors
Fundamental frequency wattless current from lamps

Fig. 4. Front End View of Three-dimensional Diagram Shown in Fig. 3

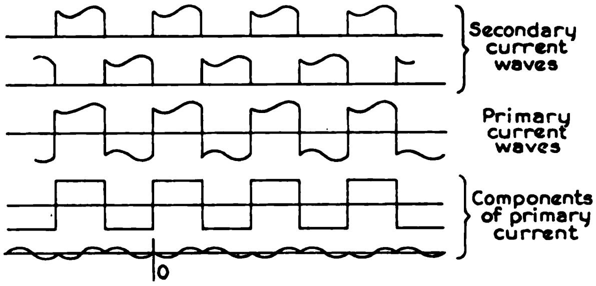

Secondary current waves
Primary current waves
Components of primary current
0

Fig. 5. Some Normal Components of Rectifier Current Waves

Fig. 3 shows such a vector diagram. The two fundamental-frequency components are drawn in a plane (top of the large block) while the harmonics are represented by a vector perpendicular to the plane. Notice that the total current from the origin in corner of the large block to the point of pencil is equal to the square root of the two unity power-factor fundamental-frequency currents added algebraically and squared, plus the two zero power-factor fundamental-frequency currents similarly treated, plus the square of the lumped harmonic currents. An end view of the diagram is particularly interesting. It may be shown in one plane as in Fig. 4, which indicates that if the wattless current from the motor is relatively large the only portion of the lamp wattless current which is effective in producing ri^2 losses in the supply system is the fundamental-frequency component.

In general, the harmonic currents from various loads will tend to neutralize each other. If a three-phase system be uniformly loaded with lamps, the third harmonics and all multiples will circulate through the lamps and will not appear in the line currents. Also, there is no reason why harmonic currents need be carried back to the ultimate source of power. All rotating machinery will act as a by-pass for these currents, each machine taking a small amount in addition to its own current. The resultant heating of the machines will be extremely small.

In analyzing a particular device very interesting problems frequently arise. In the primary-current wave of a rectifier circuit there will be square blocks of current of the form shown in Fig. 5, while the direct-current choke ripple allows a scalloped-shape wave to flow in addition. If, for purposes of analysis the origin is taken as shown at O, the symmetry of the two curves is of a different nature which gives all sine terms in one case and all cosine terms in the other, and there is no mutual effect due to the harmonics from these two sources.

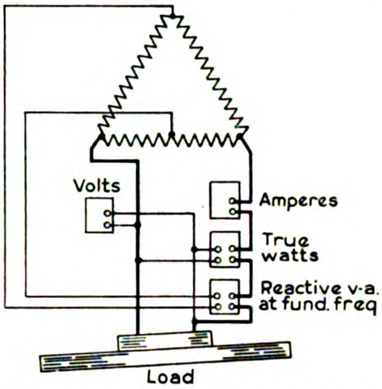


Fig. 6. Measurement of Two Components of Current. From these and the total current the third component is calculated

For the purpose of test, a device may be examined in any of the three following ways:

(1). Oscillograms may be taken and analyzed.

(2). Each part of the circuit may be tested separately and its effect on the whole calculated.

(3). The three components of current may be measured with considerable directness by using a three-phase source of power.

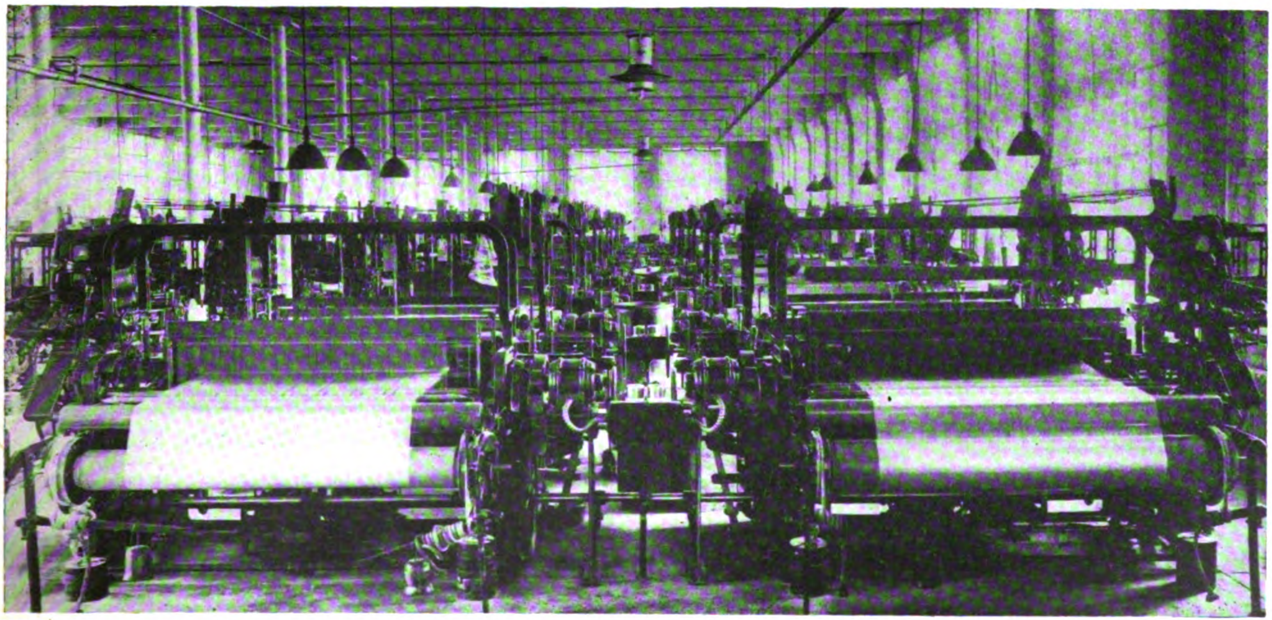
All three methods are useful but consideration will be limited to the last. If a single-phase device is connected across one side of a three-phase line as in Fig. 6, it is easy to measure the total volt-amperes and true watts consumed. In addition, the zero power-factor fundamental-frequency current is almost as readily determined. All that is required is a second wattmeter with current coil in series with the lamp and potential coil connected across a quadrature voltage of any known magnitude elsewhere in the three-phase circuit. A convenient place to obtain this quadrature voltage is from the third line to the center tap of an auto-transformer connected across the lamp as shown.

The harmonics are calculated from these figures; squaring both unity power-factor and zero power-factor fundamental-frequency components of current, subtracting these from the mean square of the total current and extracting the square root—or in mathematical notation:

$$I_{\text{total}} = \sqrt{I^2_{1\text{ p-f.}} + I^2_{0\text{ p-f.}} + I^2_{\text{harmonics}}}$$

From the data thus obtained a three-dimensional model may be built as in Fig. 3, or diagrams such as Fig. 4 may be drawn to illustrate the performance in specific cases.

A Multitude of Motors



Recent and Possible Future Developments Affecting the Economics of Large Steam Turbine Practice in the United States

PART II

By G. B. WARREN
Turbine Engineering Department, General Electric Company

PRESENT TREND

THE present trend is undoubtedly toward higher pressures. Whether it will continue in this direction depends upon the operating experience which will be obtained during the next year with those plants that are going into service, and upon the reduction in first cost which can be effected in the higher-pressure plants as more experience is gained in design, manufacture, and installation.

Resuperheating seems to be gaining ground and will probably remain as a permanent feature of a large portion of the new designs. This is shown in Fig. 24. The gain due to resuperheating is reduced by its combination with the regenerative feed-water heating cycle and high feed-water temperatures.

Opinion is still divided as to the merits of resuperheating by means of high-pressure steam. With 600 lb. per sq. in. initial pressure, its effect on the economy is rather slight but its effect upon the operating life of the low-pressure blading is no doubt considerable by virtue of the drying of the steam. Furthermore, the operational difficulties may be less than with boiler resuperheat, and it simplifies appreciably the piping design. Considering only the resultant thermal gain, it is rather expensive.

The recent increases in operating steam temperatures from 750 deg. F. (the previously accepted upper practical limit) to 825 deg. F. operating and 850 deg. F. maximum (to which both boiler and turbine manufacturers in this country are now willing to go) may somewhat reduce the number of resuperheat installations. Resuperheating to the higher temperatures, however, will give practically the same relative gain in economy. There is a definite tendency, however, on the part of some plant designers to object to the complications brought about by resuperheating. This group will probably raise the pressure as the temperature limit is raised so as to limit to a reasonably small amount the moisture in the exhaust, and so get as good economy as possible from a relatively simple plant.

New plants with units of 10,000 kw. or more usually have at least three stages of feed-water heating, and there is a definite tendency toward four and even five feed-water heaters in order to make full use of the savings possible in the regenerative feed-water heating cycle. As pressures increase six or seven steps may possibly be warranted. If the contact heater system now being tried in the Jersey Central Plant works out well, it may so reduce the cost as to permit an increasing number of steps being used generally.

Formerly a turbine was simply a prime mover coupled to a steam pipe on one end, a condenser on the other, and driving a generator. Now it is an intimate and closely tied-in part of the entire power plant. The complexity of the modern high-pressure resuperheating and regenerative plant makes it necessary that the turbine should be considered and designed as a part of the entire plant. What may be right for the turbine alone may not be best for the entire plant, and *vice versa*. The best solutions can be obtained only by taking all of the factors into consideration. This is being done by the engineers responsible for modern power-plant designs.

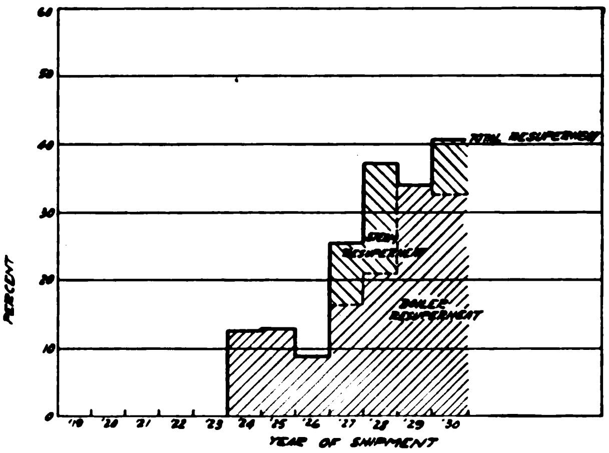


Fig. 24. Capacity of General Electric Steam Turbines Built for Resuperheating as Percentage of Total Capacity Built Each Year

PROBABLE IMMEDIATE FUTURE TREND

The remarks immediately following are not based so much upon a definitely carried out study as upon a survey of the opinions and conclusions of many engineers and groups having to do with power-plant designs and with whom the General Electric Company has had to deal. Many of these groups have conducted and are continuing to conduct exhaustive studies as to the best steam conditions. These remarks then represent primarily American conditions.

A pressure of 400 lb. per sq. in. and initial temperature of 750 deg. F., together with four feed-water heaters, will continue to serve a number of stations having units of 10,000 to 50,000 kw. with occasional larger units. This will be particularly true of those with units under 35,000-kw. capacity. With coal at $4 per ton, or under, and a load-factor under 50 per cent, this type of station will produce power at nearly as low an overall cost (including fixed charges) as can now be obtained by any existing steam cycle from plants with this size of unit. Its reliability is unexcelled, its operation and design simple, and additions can be made in the shortest possible time because the parts are largely standard. Most of these turbines will be one-cylinder machines.

For larger units, which are to be installed as additions to existing stations, the same remarks may apply for some time yet to come.

A pressure of 600 lb. per sq. in. with resuperheating may be regarded to some extent as a necessary transition stage. The equipment is all special, almost as expensive as for 1200 lb. per sq. in. pressure,. but without the possible better economy of the higher pressure. Additional installations will probably be made in existing stations, but it is improbable that new stations will be built for these conditions.

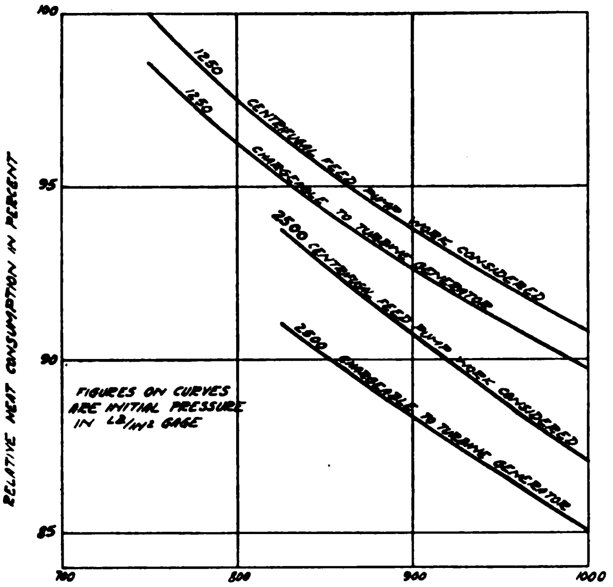


Fig. 25. Variation of Heat Consumption with Temperature, One Resuperheat Cycle

A pressure of 600 lb. per sq. in. with 825 deg. F. initial temperature but without resuperheat appears to be a very promising condition for capacities from 25,000 to 125,000 kw. One and two-cylinder, single-shaft units probably will be built. The changes which it is necessary to make in a 400-lb. per sq. in. 750-deg. F. turbine for 825-deg. F. operation will generally adapt the turbine for 600-lb. per sq. in. operation. The economy of such a cycle lies intermediate between the 400-lb. per sq. in. 750-deg. F. non-resuperheat and the 1250-lb. per sq. in. 750-deg. F. cycle with boiler resuperheating, and permits much simpler plant design and operation. The 825-deg. F. temperature reduces the moisture in the last stage to the usual values.

A pressure of 1250 lb. per sq. in., 750 deg. F. initial and resuperheat temperature, with four to five feed-water heaters and the resuperheat pressure at from 300 to 400 lb. per sq. in. has been for two or three years the accepted high-pressure cycle. It will probably continue to be for several years, although there is a definite tendency to raise the temperature to 825 deg. F. both on the initial and resuperheat temperatures. The 1250-lb. per sq. in. resuperheat plant, at this time, appears to cost from 6 to 10 per cent more, depending upon the size and other conditions, than the 400-lb. per sq. in. plant at the same temperature. It has about 13 per cent better economy. If the fuel cost and load-factor of the 400-lb. per sq. in. plant are such that its fixed charges are about equal to its fuel charges then it begins to pay to put in the high-pressure plant. This seems to be the case in many new plants and some new additions to old plants where units of 50,000 kw. and over can be installed.

The 300 to 400-lb. per sq. in. resuperheat pressure commonly used puts the 1250-lb. per sq. in. plant in an advantageous position so far as turbine cost is concerned, for units under 90,000 kw. at 60 cycles and for units under 125,000 kw. at 50 cycles. This is because the low-pressure unit can be the usual 300 to 400-lb. per sq. in. unit made from more or less standard designs, whereas the high-pressure unit can be run at 3000 to 3600 r.p.m. Higher temperatures will of course bring modifications which will increase the cost.

RELATIVE ECONOMIES OF PRESENT AND POSSIBLE FUTURE STEAM CYCLES

Many cycles are of interest and studies have been made to show the economies from the turbine standpoint which can reasonably be expected of a number of different combinations.

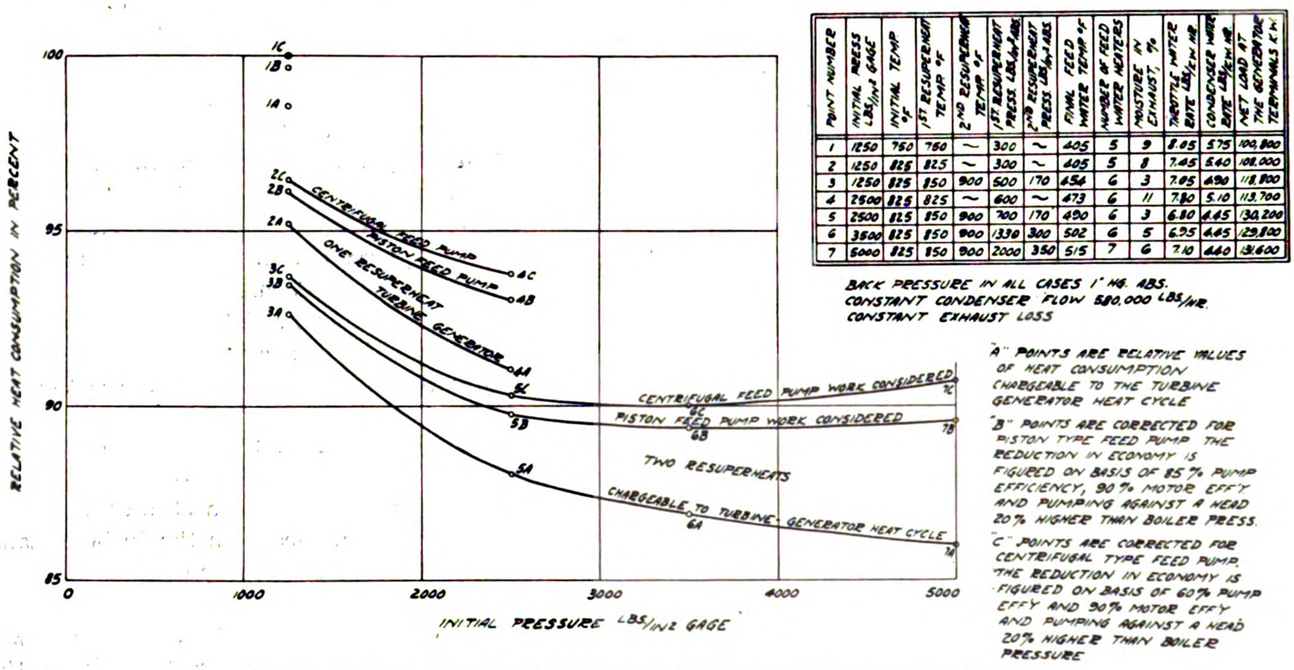
The cycles studied have been chosen with a view to their advantages and possible practicability rather than simply with the idea of showing the change in economy with a single variable. In each case, fairly detailed turbine designs and internal efficiency values have been worked out. Careful attention has been given to packing leakage. The machines are all 100,000 to 150,000-kw. tandem-compound machines with the exception of the 3500 and 5000-lb. per sq. in. pressure cycles which have 3600-r.p.m. high-pressure turbines.

The fact that very high temperatures have been studied does not imply that it is felt that the industry is now in a position to try them on a commercial scale.

Careful account has been taken, as can be seen in the charts in this article, of the effect of the increased auxiliary power required as the pressure is increased.

The normal figure for heat consumption of the turbine generator as given in the "A" points of Fig. 26 is based upon the total heat in the throttle flow, plus the heat put in by the resuperheater, minus the heat of the liquid returned by the feed-water at the top heater conditions. To get the heat consumption, taking the feed pump into consideration, the station output is charged with all of the energy drawn from the switchboard by the pump motor and that fraction of this energy returned to the boiler by the liquid is credited to it and does not have to be supplied by the furnace. In the case of the centrifugal pump the entire pump-shaft energy, *i.e.*, all the motor power less motor losses, is credited to the boiler; while in the case of the piston pump it is assumed that all losses are external to the pump so that the boiler can be credited only with the theoretical feed-pump work.

Data as to turbine and station costs are not available so as yet it is impossible to do more than form a judgment of the relative commercial advantages. No attempt has been made to analyze the data for smaller machines, but the results for capacities down to 50,000 kw., where the high-pressure turbine would be run at 3000 or 3600 r.p.m., would not be appreciably different.



POINT NUMBER	INITIAL PRESS LBS/IN² GAGE	INITIAL TEMP °F	1ST RESUPERHEAT TEMP °F	2ND RESUPERHEAT TEMP °F	1ST RESUPERHEAT PRESS LBS/IN² ABS	2ND RESUPERHEAT PRESS LBS/IN² ABS	FINAL FEED WATER TEMP °F	NUMBER OF FEED WATER HEATERS	MOISTURE IN EXHAUST, %	THROTTLE WATER RATE LBS/KW HR	CONDENSER WATER RATE LBS/KW HR	NET LOAD AT THE GENERATOR TERMINALS KW
1	1250	750	750	~	300	~	405	5	9	8.05	5.75	100,800
2	1250	825	825	~	300	~	405	5	8	7.45	5.40	108,000
3	1250	825	850	900	500	170	454	6	3	7.05	4.90	118,800
4	2500	825	825	~	600	~	473	6	11	7.80	5.10	113,700
5	2500	825	850	900	700	170	490	6	3	6.80	4.45	130,200
6	3500	825	850	900	1330	300	502	6	5	6.95	4.45	129,800
7	5000	825	850	900	2000	350	515	7	6	7.10	4.40	131,600

BACK PRESSURE IN ALL CASES 1" HG. ABS.
CONSTANT CONDENSER FLOW 580,000 LBS/HR.
CONSTANT EXHAUST LOSS

"A" POINTS ARE RELATIVE VALUES OF HEAT CONSUMPTION CHARGEABLE TO THE TURBINE GENERATOR HEAT CYCLE

"B" POINTS ARE CORRECTED FOR PISTON TYPE FEED PUMP. THE REDUCTION IN ECONOMY IS FIGURED ON BASIS OF 85% PUMP EFFICIENCY, 90% MOTOR EFF'Y AND PUMPING AGAINST A HEAD 20% HIGHER THAN BOILER PRESS.

"C" POINTS ARE CORRECTED FOR CENTRIFUGAL TYPE FEED PUMP. THE REDUCTION IN ECONOMY IS FIGURED ON BASIS OF 60% PUMP EFF'Y AND 90% MOTOR EFF'Y AND PUMPING AGAINST A HEAD 20% HIGHER THAN BOILER PRESSURE

Fig. 26. Variation of Heat Consumption with Initial Pressure for Various Resuperheating Cycles. Turbine efficiencies on a comparable basis

The results are shown in Figs. 25, 26, and 27. The cycles which seem at the moment to have a commercial future are grouped together in Fig. 28. Overall station economies have been figured, based upon certain assumptions as to auxiliary power and boiler efficiency. For comparison, two mercury turbine cycles are included. The low auxiliary power load of this cycle is particularly noteworthy.

The general assumptions which have been used in these studies, the results of which are shown in Figs. 25, 26, 27, and 28 are as follows:

(1). Constant weight flow to condenser of 580,000 lb. per hour and constant leaving loss in B.t.u.'s per pound of condenser flow. Throttle flow increased by amount of extraction. This gives an increase in turbine capacity for the more efficient cycles, as shown in Fig. 27. The values shown in Fig. 28 have been corrected to a fixed turbine capacity of 100,000 kw. for the different cycles, but still with constant leaving loss, the turbines operating at three-fourths rated load.

(2). The efficiencies have been carefully adjusted to take into account the design of a machine necessary for the particular conditions under consideration, with the exception of the cycles using 1000 deg. F. temperature. Here the efficiency of the high-temperature end has not been lowered as would be necessary today to meet the handicap in construction imposed by present knowledge of the behavior of materials at these temperatures. The figures for 1000-deg. F. performance are therefore probably somewhat better than could be obtained now.

The effect of packing leakage and moisture losses have been carefully considered.

(3). Reheater pressure drop including piping and intercepting valve, seven per cent.

(4). Ten per cent pressure drop to extraction heaters where extracting from turbine stages and eight per cent drop where extracting from cross overs.

(5). Terminal difference in heaters, five deg. F.

(6). Drips from all heaters pumped into boiler side of feed line at heater.

(7). Extraction pressures selected to give practically equal extraction to all heaters at the layout conditions.

(8). Reheat pressure at point where experience is indicating it should be placed for most economical overall conditions. This is in general at a pressure at three-fourths load slightly in excess of that for greatest efficiency.

The curves are in general self-explanatory and give the conclusions better than words can do.

For ready reference the following figures are of interest to remember, and are all based upon regenerative cycles with feed pump taken into consideration:

(1). Each 25 deg. F. increase in temperature gives about one per cent reduction in heat consumption.

(2). A change from 400-lb. per sq. in. 750-deg. F. initial non-resuperheat to 1250-lb. per sq. in. 750-deg. F. initial and resuperheat temperature gives about 12 to 13 per cent reduction in heat consumption.

(3). A change of initial pressure from 1250 to 2500 lb. per sq. in. gives three per cent reduction in heat consumption with a one-resuperheat cycle and 3.7 per cent better with a two-resuperheat cycle.

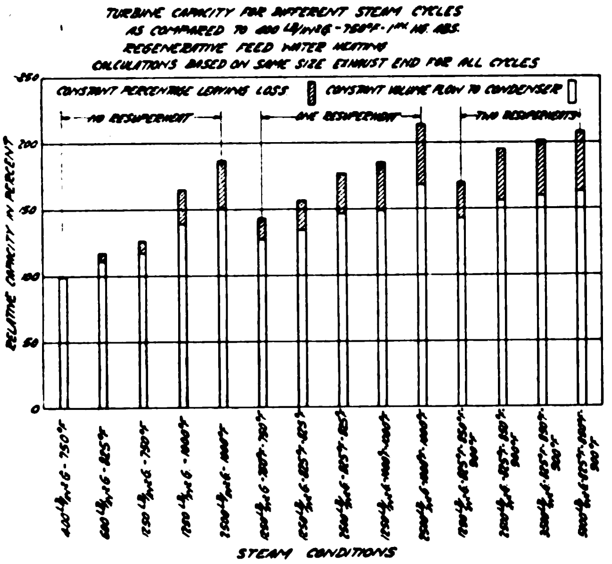


Fig. 27. Relative Turbine Capacity for Different Cycles Based on Using the Same Turbine Exhaust End

(4). A change of initial pressure from 2500 to 3500 lb. per sq. in. gives no gain with two resuperheatings to 850 deg. and 900 deg. F. respectively and a further change to 5000 lb. per sq. in. shows a loss.

(5). The exact thermal gain due to the first resuperheating to the initial temperature is rather difficult to evaluate exactly, owing to the uncertainty as to the exact amount of moisture extraction in the high-pressure non-resuperheat cycle. The gain is probably from 3 to 4½ per cent.

(6). Two resuperheatings with five to six feed-water heaters to 460 deg. F. gives 2.25 per cent gain at 1250 lb. per sq. in., and 3.00 per cent gain at 2500 lb. per sq. in. as compared to one resuperheating.

The values in both items (5) and (6) take into account the pressure drop through the resuperheaters. The radiation losses in the resuperheat lines do not appear to be appreciable.

Effect of New Cycles Upon Possible Capacity

Fig. 27 shows the increased capacity permitted at constant exhaust-volume flow and at constant percentage leaving loss for a given low-pressure end. The very great increase in capacity permitted is apparent. This possible "rating up" of low-pressure ends has been taken advantage of to maintain at the minimum possible figure the cost of turbines designed for higher pressures and temperatures. The possible capacity of double-flow 1500 and 1800-r.p.m. tandem-compound turbines for these higher-pressure cycles is beyond the capacity of the generators without exceeding existing last-stage bucket lengths. In the past when the actual needs for larger generator capacities have arisen, the generator designers have always met them. If still further advances prove inadvisable, the cross-compound arrangement can still be used.

Commercial Value

As higher pressures and temperatures are used, the gains for each increment are reduced and the cost of building the plant will probably be increased. This will be particularly marked on turbine costs for initial temperatures in excess of 825 deg. F., resuperheat temperatures in excess of 900 deg. F., and for pressures in excess of 1400 to 1500 lb. per sq. in. This is on the assumption that the turbines are made to utilize the higher pressure and temperature range efficiently. Unless some marked reduction can be effected in the cost of boilers by going to the drumless types at 2400 lb. per sq. in. and above, it is quite probable that 1250 lb. per sq. in. pressure represents nearly the economical limit in pressure. Similarly, unless experience with metals at high temperatures and under stress shows less creep than anticipated, or unless better materials or radical innovations in turbine design are made, 825 deg. F. initial and possibly 900 deg. F. resuperheat temperature may represent the economical limit of temperature.

Effect of More Efficient Cycles Upon Turbine Design

As pressures and temperatures are increased, the best practice at the present time is to divide the turbine into a larger number of cylinders. Several years ago it was generally the practice when attempting to figure the gain to be obtained from higher pressures to assume a very serious falling off in efficiency in the high-pressure end as the pressure was increased. As a matter of fact, in modern high-pressure turbines the high-pressure end is nearly as efficient as any other part of the turbine. This has, of course, been possible by virtue of the fact that many considerations in design point to the desirability of increasing the number of turbine cylinders somewhat as the pressure is increased. When the number of cylinders is increased, it becomes possible and desirable to increase the number of stages. The larger number of stages means smaller diameters, longer buckets, and smaller clearances in the high-pressure end, all of which make for sustained high efficiency. Whereas at the lower pressures a two-cylinder design as compared to a single-cylinder design cannot always be justified by the slight increase in efficiency, at the higher pressures, the two or three cylinder design can generally be justified on account of the larger gain in efficiency so obtained.

The smaller diameters permitted by the foregoing considerations very materially reduce the difficulties encountered in making a shell construction to withstand the higher pressures and higher temperatures.

Four problems will have to be solved to meet the requirements of higher-temperature operation:

(1). Reduction of stresses so as to stay below the allowable creep limit.

(2). The use of better materials for high temperatures in shells, nozzles, shafts, wheels, and buckets.

(3). The design of parts so as to reduce as much as possible the number and size of parts subjected to the high temperatures.

(4). The design of parts subjected to high temperatures so that a reasonable amount of distortion will not jeopardize the operation of the machine.

These problems can be met. In view of the tremendous investments involved, however, it is a case of proceeding cautiously enough to permit each step being a complete commercial success. Furthermore, since our knowledge of the behavior of materials over long periods of time at high temperatures under stress is as yet so meager, it is very difficult to determine just how conservative to be. To be too conservative means that the cost of the turbine will be out of proportion to the saving achieved by the higher temperature, whereas not to be conservative enough would be fatal to reliable operation. Much experience will have to be accumulated before the turbine designer knows exactly where the proper point is.

TURBINE EFFICIENCY

Turbine-generator overall efficiencies and the turbine internal efficiencies have been increasing steadily during the past. So many variables enter into this situation that it is impossible to set down exact values. The internal efficiencies have been increased by virtue of better design, extraction of an appreciable fraction of moisture, multi-cylinder design with resultant increase in number of stages, increased capacity, and increased temperatures.

The overall efficiencies have been increasing as a result of the better internal efficiencies, better generator efficiencies, and reduced throttle and exhaust hood losses. Somewhat smaller gains have been made in a few cases on account of the increased leaving losses which have been accepted in order to get a greater output from a given low pressure end. In many other cases, however, the leaving losses have been reduced.

Considerable progress has been made in America toward securing flat load-economy curves over a wide range of load by providing many points of admission under the control of the governor. This, to some extent, complicates the design. Fortunately the use of more efficient cycles gives a flatter load curve inherently and a smaller number of admission valves may suffice. This may tend to simplify the design and offset to some extent the other difficulties of the higher-pressure front end.

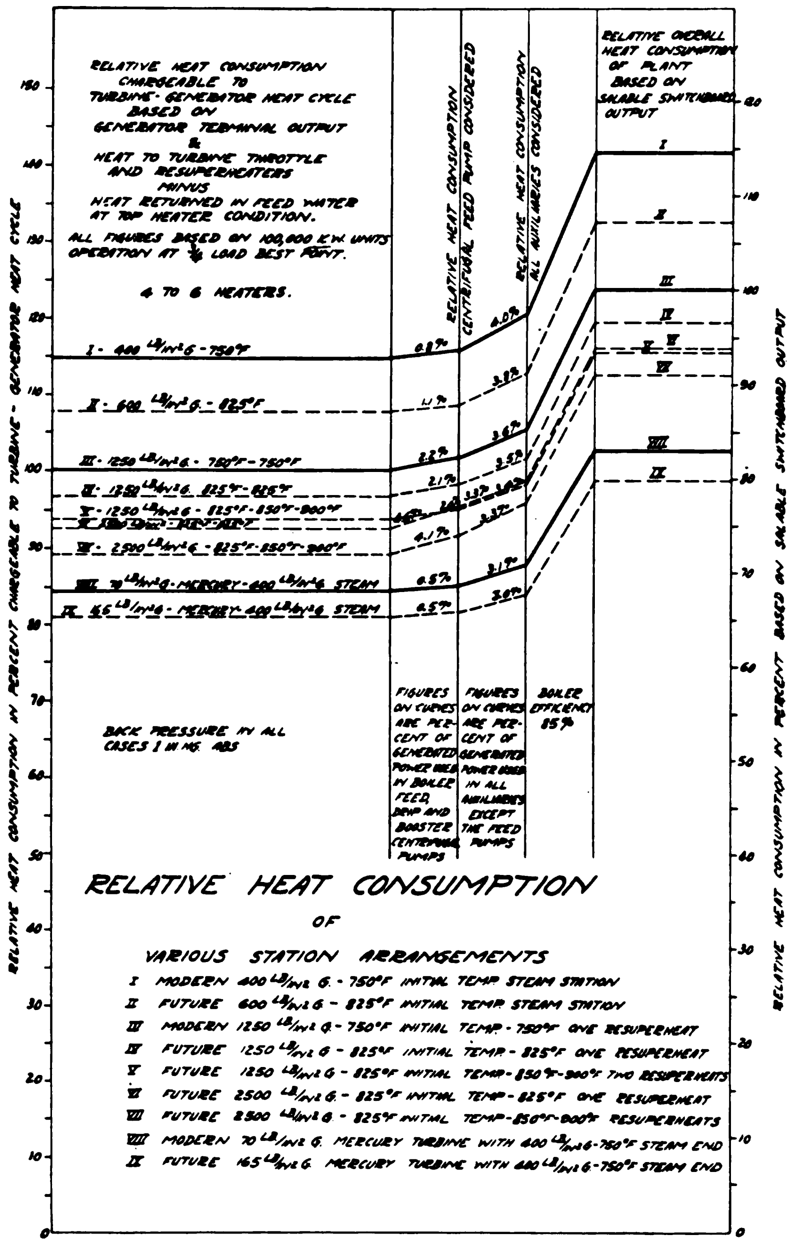


Fig. 28. Relative Heat Consumption of Various Station Arrangements

The rapid progress which has been made in past years in steam-turbine design has been the joint result of theoretical investigation, research, experience, and last but most important of all, careful, thorough, well-thought-out design. Only by this latter have the full inherent possibilities of the machine been brought out.

The increasing complexity, pressures, and temperatures of the modern steam cycles, together with the demand for higher efficiency, capacity, and reliability are forcing a refinement of mechanical design and construction which was unknown a few years ago. The modern steam turbine is now the most refined and productive large machine in the world.

CONCLUSIONS

Surveying the steam turbine trends there are certain things which stand out.

The average capacity of the turbines built each year will probably continue to increase. Such an increase will probably bring both reduced station first cost and better economy. The maximum size of single units will continue to increase and may reach 200,000 kw., for a single-shaft 1800-r.p.m. hydrogen-cooled generator unit. Such a unit will have a very favorable first cost and economy. Two-generator cross-compound machines will be very much in favor where length is a limitation. It is yet too early to predict whether the three-cylinder triple-compound turbine for very large sizes will be used extensively. The complexity of control works against it as compared to the simpler two-cylinder cross-compound vertical-compound or tandem-compound unit. It is also too early to judge the future use of the vertical-compound unit, but if operating experience bears out present expectations it is safe to say that the economies in space and foundation which it permits will make it an important type.

The use of one high-pressure 3000 or 3600-r.p.m. back-pressure turbine for each high-pressure boiler exhausting at fixed back pressure into the lower-pressure headers feeding the 200 or 400 lb. per sq. in. turbines is likewise a design which must be further compared in actual operation with the tandem or cross-compound arrangement with variable cross-over pressure before a final judgment is made. With an increase in pressure to 2400 lb. per sq. in. it may have very definite advantages.

Steam conditions will probably continue to change, with steadily more efficient conditions being used. The calculations given in a preceding part of this article seem to indicate quite clearly that, with present temperature limitations, 2500 lb. per sq. in. steam pressure is nearly the economical limit. If this high pressure can be combined with 1000 deg. F. initial temperature and six or seven stages of feed-water heating, without resuperheating, it will be possible to produce a unit with a very high efficiency and great simplicity. In the case of large cross-compound units with three or four cylinders, and two or more boilers per turbine, two resuperheats may prove practical; *i.e.*, where divisions would be made in the turbine for other reasons as well, and where the two resuperheaters can be put into separate boilers.

The next step in economy beyond the cycles shown in this article will probably result from the use of the mercury-vapor steam cycle. It offers more promise than anything else in the field. This cycle has been completely discussed by W. L. R. Emmet and others in previous World Power Conference Papers and other publications. It promises from 10 to 15 per cent better overall economy than the best of the steam cycles considered here, a part of which comes from reduced auxiliary power.

The efficiency of the turbine itself will continue to be improved by more scientific and more experienced design. We have not yet come to the end here, although the margin of possible gain is not so great as it formerly was.

If as more experience is gained with boiler, auxiliary, and turbine designs for higher pressures and temperatures, the first cost and maintenance of these elements of the station should be reduced, then it will make the higher-efficiency designs more feasible economically.

The cost of power is approximately equally divided between fixed charges and operating costs with the fixed costs tending to be the larger. Most of the operating cost is fuel. As the lower limit of economy is approached, the only way in which the cost of power can be further reduced is to reduce the fixed charges. This is undoubtedly to be the next big effort and this means that the first costs of plants must be reduced.

Turbine costs and turbine-room costs become substantially less as the turbine unit capacity becomes larger. Boiler and auxiliary costs show the same trend. This is probably the largest single factor which will be available for reducing costs. Much may be done by simplifying the entire plant design. Water-power plants are pointing the way toward outdoor installations and many engineers are seriously considering that this may be the next step in steam plants. With automatic control an already established practice, it looks entirely feasible from the operation standpoint.

However, with the approach to the ultimate economy for which a steam station can be designed, unless some radical and as yet unknown innovation is brought about, the stations which are now and in the future going into service should have a greater period of high-load-factor usefulness. Consequently stations with a relatively greater cost and greater economy can be justified more easily from the overall cost per kilowatt-hour standpoint, since the obsolescence factor in the fixed charges will be less. It will not pay to secure low first cost by building low-efficiency stations.

To sum up, there is no single trend. The power plant art is yet in a state of flux. It would be unwise to try to make a definite prediction as to what the future power plant will be like. It seems certain, however, that with the large number of able minds throughout the world working on it in the future as they have been doing in the past, and if cheap fuel resources continue to be available, the net cost of power to the electrical industry will continue to be reduced.

(*Concluded*)

A Study of Crystal Structure and Its Applications

PART XVI

CALCULATION OF CRYSTAL ORIENTATION FROM UNSYMMETRICAL LAUE PHOTOGRAPHS

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ALTHOUGH the mathematical procedure involved in the determination of a crystal orientation is considerably simplified if a symmetrical Laue photograph can be used as the starting point, such a photograph is by no means necessary. In many cases the obtaining of such a photograph would be a great inconvenience, or, in the case of coarsely polycrystalline specimens, it might be an impossibility. Many x-ray laboratories, also, may not have available the high-voltage equipment for the rapid preparation of penetrating ray photographs. Therefore, the most generally useful method of obtaining a crystal orientation will be one applicable to unsymmetrical photographs.

The mathematical solution of such photographs will be the subject of this Part. As in the previous Parts, the solution will be shown with particular reference to the body-centered cubic system of crystals. The steps in the solution will in general resemble those of the previous Part. There are, however, some differences. In working with unsymmetrical photographs, it is not so convenient to establish the identity of a zone. The identity of separate reflections is of greater importance, without reference to the zone in which they may be situated, otherwise, very complicated axes of rotation must be used. Another difference is in the manner of handling the rotation of the crystal from its standard position. The easier course to pursue with unsymmetrical photographs is to regard a pair of identified reflections as defining two axes of rotation of a crystal. The final position of the crystal must be reached about both axes simultaneously.

Establishing the Identity of the Plane Reflections

Fig. 113 represents an unsymmetrical Laue photograph ABCD lying on its gnomonic projection *EFGH*. The crystal is situated at *N*. The lettering of the spots and the angles has been made to conform to that used in Fig. 103, Part XIV, which is the analogous symmetrical case. The angles θ_1 and $90-\theta_1$ refer to spot *M* on the Laue photograph and its gnomonic projection *P*; θ_2 and $90-\theta_2$ refer similarly to *L* and *Q*. By consideration of the geometrical relations involved, it is evident that:

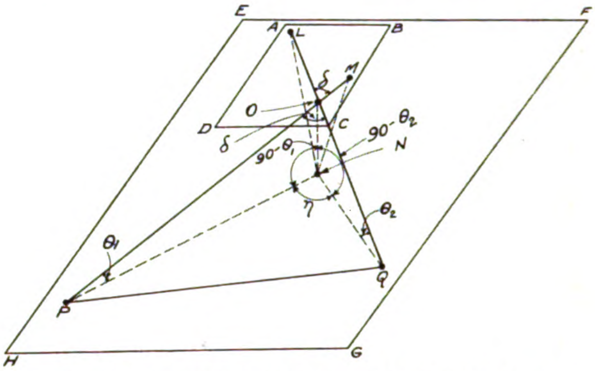


Fig. 113. Method of Calculating Angles Between Plane Perpendiculars from Laue Spots of Unsymmetrical Photographs

$$OP = NP \cos\theta_1 \qquad OQ = NQ \cos\theta_2 \qquad (115)$$

and

$$ON/OP = \tan\theta_1 \qquad ON/OQ = \tan\theta_2 \qquad (116)$$

$$ON/NP = \cos(90-\theta_1) = \sin\theta_1 \qquad ON/NQ = \sin\theta_2 \qquad (117)$$

In the triangle *POQ*,

$$(PQ)^2 = (OP)^2 + (OQ)^2 - 2\,(OP)\,(OQ)\cos\delta$$

In the triangle *PNQ*,

$$(PQ)^2 = (NP)^2 + (NQ)^2 - 2\,(NP)\,(NQ)\cos\eta$$

References made to material hitherto published in this series of articles may be readily located from the following table:

Part	*Issue*	*Figs.*	*Equations*	*Tables*	*Footnotes*
Part I	Nov., 1924 p. 742	1 and 2	1 to 16	I and II	1 to 21
Part II	Dec., 1924 p. 795	3 to 10	17 to 32	III	22 to 27
Part III	Feb., 1925 p. 129	11 to 22	33 to 37	IV	28 to 42
Part IV	Apr., 1925 p. 258	23 to 28	38 to 41	None	43 to 48
Part V	May, 1925 p. 342	29 to 35	None	None	49
Part VI	Aug., 1925 p. 286	36 to 51	42	V to VII	50 to 58
Part VII	Oct., 1925 p. 721	52 to 59	43 to 47	VIII and IX	59 to 65
Part VIII	Feb., 1926 p. 118	60 to 67	48	X to XIII	66 to 82
Part IX	Apr., 1926 p. 274	68 and 69	49 to 56	XIV to XXVI	83 to 117
Part X	Aug., 1926 p. 580	70 and 71	57 to 66	XXVII to XXXI	118 to 131
Part XI	Sept., 1928 p. 496	72 to 77.	67 to 84	XXXII and XXXIII	132 to 139
Part XII	Nov., 1928 p. 612	78 to 92	85 to 98	XXXIV and XXXV	140 to 162
Part XIII	Oct., 1929 p. 552	93 to 97	None	None	163 to 178
Part XIV	May, 1930 p. 308	98 to 105	99 to 107	XXXVI to XL	179 to 185
Part XV	July, 1930 p. 412	106 to 112	108 to 114	None	186 to 188

Equating the two values of $(PQ)^2$ thus obtained, and substituting for OP, OQ, NP, and NQ the values shown in Equations (115), (116), and (117), the following Equation results:

$$\frac{(ON)^2}{\tan^2\theta_1}+\frac{(ON)^2}{\tan^2\theta_2}-\frac{2\,(ON)^2\cos\delta}{\tan\theta_1\tan\theta_2}=\frac{(ON)^2}{\sin^2\theta_1}+\frac{(ON)^2}{\sin^2\theta_2}-\frac{2\,(ON)^2\cos\eta}{\sin\theta_1\sin\theta_2}$$

which upon division by $(ON)^2$ and rearrangement of terms becomes:

$$\frac{\cos^2\theta_1}{\sin^2\theta_1}+\frac{\cos^2\theta_2}{\sin^2\theta_2}-\frac{1}{\sin^2\theta_1}-\frac{1}{\sin^2\theta_2}=\frac{2\cos\theta_1\cos\theta_2\cos\delta}{\sin\theta_1\sin\theta_2}-\frac{2\cos\eta}{\sin\theta_1\sin\theta_2}$$

or

$$\frac{\cos^2\theta_1-1}{\sin^2\theta_1}+\frac{\cos^2\theta_2-1}{\sin^2\theta_2}=\frac{2\cos\theta_1\cos\theta_2\cos\delta-2\cos\eta}{\sin\theta_1\sin\theta_2}$$

Substituting the value of $\sin^2\theta$ for $\cos^2\theta-1$, this equation becomes:

$$-2=2\,\frac{(\cos\theta_1\cos\theta_2\cos\delta-\cos\eta)}{\sin\theta_1\sin\theta_2}$$

which gives as the final Equation:

$$\cos\eta=\sin\theta_1\sin\theta_2+\cos\theta_1\cos\theta_2\cos\delta \quad (118)$$

where η is the angle subtended by the plane perpendiculars under consideration, and δ is the projection of this angle on the plane of the projection; θ_1 and θ_2 are the angles existing between the x-ray beam and the reflecting planes.

All the quantities on the right of Equation (118) can be obtained for any pair of spots on a Laue photograph.

TABLE XLI

TABLE OF INTERPERPENDICULAR ANGLES OF THE BODY-CENTERED CUBIC LATTICE IN ORDER OF INCREASING ANGLE

Angle in Deg. and Min.	Plane-Pair	Angle in Deg. and Min.	Plane-Pair	Angle in Deg. and Min.	Plane-Pair	Angle in Deg. and Min.	Plane-Pair	Angle in Deg. and Min.	Plane-Pair	Angle in Deg. and Min.	Plane-Pair
8° 8′	201-310	46° 8′	411-321	70° 32′	211-211	[90°]	310-110	[109° 28′]	111-111	[132°]32′	321-310
10° 54′	321-211	47° 28′	321-310		111-111		111-110		411-110	133° 32′	411-321
13° 30′	321-321	40′	411-211		411-110		111-211	110° 11′	411-321	135°	110-100
14° 19′	411-310	49′	321-321	54′	321-211		321-211	111° 1′	201-321		201-310
15° 48′	411-211	52′	310-110	71° 34′	310-100		321-310	25′	111-310	136° 55′	111-310
17° 2′	201-321	48° 11′	211-211		201-110		321-111	58′	321-321		201-211
18° 26′	310-100	49° 6′	321-211		201-411		411-110	112° 12′	321-110	137° 33′	201-411
	201-110	48′	310-211	72° 2′	321-111		201-100		411-321	138° 14′	411-321
	201-411	53′	411-111	32′	310-310		201-211	52′	411-411	25′	321-321
19° 6′	321-110	50° 46′	201-110	36′	321-321		201-321	113° 35′	201-201	139° 6′	321-110
	321-411		201-411	39′	411-310	93° 11′	411-411	114° 6′	211-100	31′	321-310
28′	111-211	58′	411-321	73° 13′	211-110	37′	411-321	115°	321-310	48′	321-211
	411-100	51° 53′	321-111		411-211	94° 16′	411-310	6′	201-310	40° 46′	201-111
21° 37′	321-310	53° 8′	310-310	34′	201-310	17′	321-321	116° 34′	310-110	141° 2′	411-411
22° 13′	321-111		201-201	74° 12′	411-111	51′	321-310		201-100	143° 8′	310-310
24° 5′	201-211	15′	321-321	30′	321-100	95° 31′	411-211	40′	321-321		201-201
25° 21′	310-211	22′	201-321	75° 2′	310-211	45′	310-310	118° 8′	111-211	18′	321-100
51′	310-310	44°	321-310		201-111	96° 3′	201-411	34′	201-321	144° 44′	411-111
26° 10′	321-321	54° 44′	211-110	19′	321-310	16′	321-211	46′	411-211		211-100
34′	310-110		111-100	24′	411-321	52′	201-321	119° 9′	321-310	58′	411-321
	201-100		411-211	76° 22′	411-100	97° 25′	310-211	120°	110-110	145° 4′	411-310
27° 34′	411-411	55° 28′	411-321	77° 5′	310-110	98° 8′	201-310		211-211	22′	321-321
29° 12′	321-211	56° 47′	201-211	24′	321-211	34′	411-310		411-110	146° 26′	411-110
30° 1′	211-110	57′	321-211	50′	201-411	36′	321-321		411-411	27′	211-211
31° 57′	201-310	57° 41′	321-100	78° 28′	201-201	99° 36′	211-211	121° 6′	310-211	47′	201-321
32° 19′	321-310	58° 26′	321-321	79° 7′	321-110	100° 31′	201-211	27′	411-310	147° 41′	321-310
33° 13′	201-321	33′	411-310		411-321	53′	321-110	34′	321-321	148° 3′	201-310
33′	211-211	54′	310-211	29′	201-211		411-321	122° 19′	321-100	149° 59′	211-110
34′	411-110	60°	211-211	80° 24′	211-211	101° 32′	201-201	123° 3′	321-211	150° 48′	321-211
34° 38′	321-321		411-110	81° 24′	321-321	102° 10′	201-411	13′	201-211	152° 26′	411-411
56′	411-310		411-411	26′	411-310	36′	321-211	124° 32′	321-110	153° 26′	310-110
35° 2′	411-321	51′	321-310	52′	201-310	55′	310-110		411-321		201-100
16′	211-100	61° 14′	411-211	82° 35′	310-211	103° 38′	411-100	125° 16′	211-110	50′	321-321
	111-110	26′	201-321	83° 8′	201-321	104° 36′	411-321		111-100	154° 9′	310-310
	411-111	52′	111-211	44′	321-211	41′	321-310		411-211	39′	310-211
36° 42′	321-100	63° 20′	321-321	57′	201-411	58′	310-211	126° 16′	321-310	155° 55′	201-211
52′	310-310	26′	310-110	84° 15′	310-310		201-111	38′	201-321	157° 47′	321-111
	201-201		201-100	29′	411-211	105° 30′	321-100	45′	321-321	158° 23′	321-310
38° 58′	411-411	64° 54′	201-310	85° 9′	321-310	48′	411-111	52′	310-310	160° 32′	111-211
39° 14′	201-111	65°	321-310	43′	321-321	106° 26′	201-310		201-201		411-100
40′	411-211	54′	211-100	44′	411-310	47′	211-110	128° 7′	321-111	54′	321-110
40° 12′	321-211	66° 25′	201-201	86° 23′	411-321		411-211	129° 2′	411-321		411-321
29′	321-310	67° 8′	411-411	49′	411-411	107° 21′	411-310	14′	201-110	161° 34′	310-100
54′	321-110	48′	321-110	90°	110-110	24′	321-321		201-411		201-110
41° 35′	321-321		411-321		100-100	28′	310-310	130° 7′	411-111		201-411
46′	411-321	68° 2′	321-321		310-310	58′	321-111	12′	310-211	162° 58′	201-321
42° 27′	201-411	35′	111-310		201-201	108° 26′	310-100	54′	321-211	164° 12′	411-211
43° 5′	111-310	59′	201-321		110-100		201-110	131° 49′	211-211	165° 41′	411-310
	201-211	69° 49′	411-321		310-100		201-411	132° 8′	310-110	166° 30′	321-321
45°	110-100				211-110	109° 6′	321-211	11′	321-321	169° 6′	321-211
	210-310					28′	211-211	20′	411-211	171° 52′	201-310

With unsymmetrical photographs as well as with symmetrical ones the best procedure is to choose spots as near the zero beam impression as possible. In accordance with the Bragg reflection law, the number of families of planes which can produce such reflections are few. This reduces considerably the number of pairs of planes which must be considered in the establishment of plane identity.

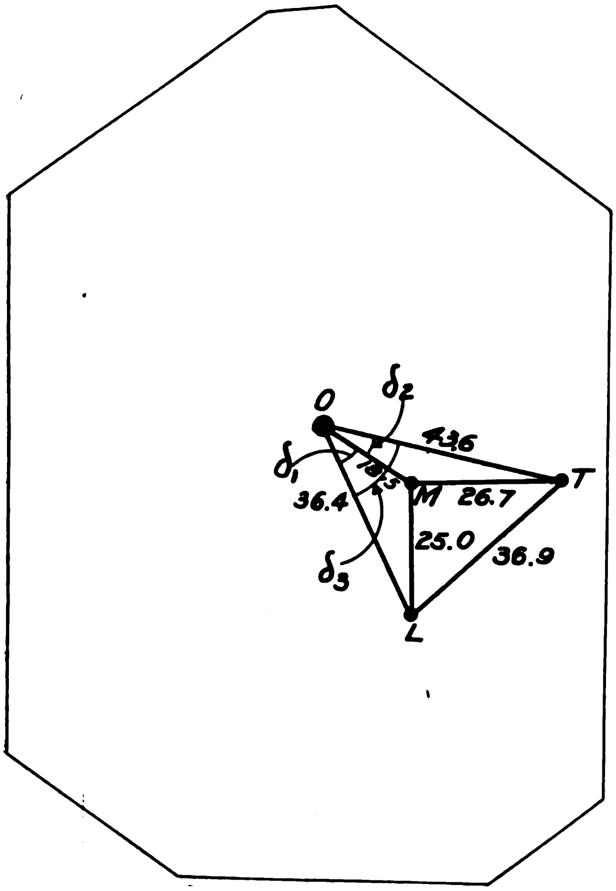


Fig. 114. Precise Measurement of the δ-angles

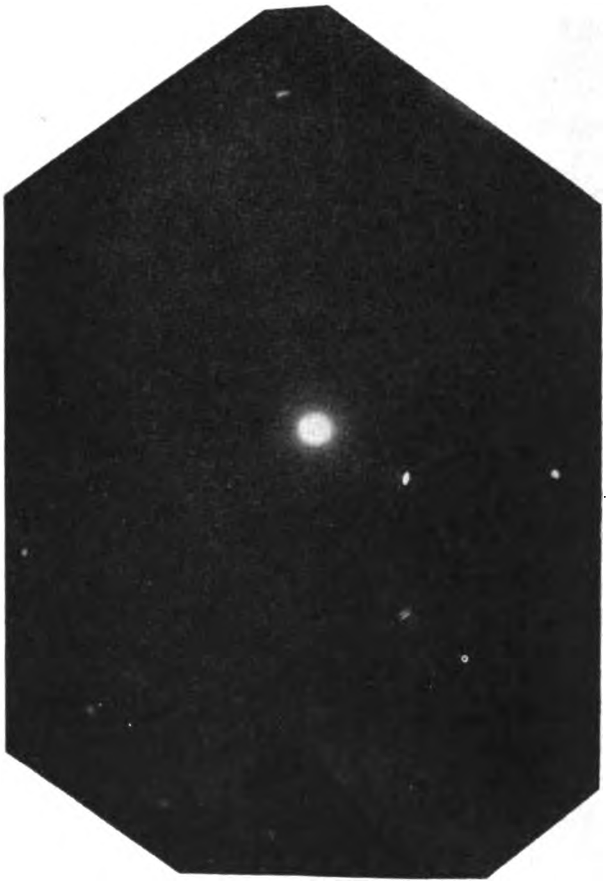


Fig. 115. Unsymmetrical Laue Photograph of a Silicon Steel Single Crystal

A pair of planes, in order to be responsible for the appearance of a pair of spots on the Laue photograph, must not only satisfy the limitations of minimum interplaner distances imposed by the Bragg reflection law, but must also give a value of the inter-perpendicular angle which satisfies Equation (118). The manner of calculating the inter-perpendicular angle between a pair of planes of known indices was shown for cubic crystals in Part XIV, together with a table containing the values for this angle yielded by pairs of planes symmetrically disposed about either the $\{100\}$ or $\{110\}$ zone axes. Now that unsymmetrically disposed pairs of planes are being considered as well, a more extensive table of interperpendicular angles is desirable. For the body-centered cubic lattice, this information is shown in Table XLI, for all planes having inter-planer distances equal to, or greater than, the (210) planes.

This Table shows that in general there is not a large interval between successive permissible values of the inter-perpendicular angle, and that, therefore, unless the choice of pairs of planes is closely limited by the Bragg reflection law, there may be an error in making this choice. Two ways of obviating this difficulty are used:

(1). By measuring the angle δ on the film more accurately.

(2) By considering three spots on the film instead of two.

In determining the angle δ from symmetrical films, measurement of this angle with a protractor furnished a sufficiently precise value. With symmetrical films, several δ-angles in the same zone are thus measured, and several inter-perpendicular angles are calculated from them. All these calculated values must agree with the values obtained from the table for that zone, and consequently, each value does not need to be determined so accurately. This condition is no longer applicable in the case of unsymmetrical photographs. Each value of the angle δ obtained from the film may apply to a different zone of planes. Each value must, therefore, be determined as precisely as possible.

For this reason, protractor measurement of the δ-angles is not practiced on unsymmetrical films. Instead the following procedure is used (see Fig. 114):

With the dividers, the distances *LM*, *LO*, and *MO* are measured. From these distances, δ_1 can be calculated in accordance with the usual law of triangles:

$$(LM)^2 = (LO)^2 + (MO)^2 - 2\ (LO)\ (MO)\cos\delta_1$$

But even when this value of δ has been calculated as precisely as possible, and the Bragg reflection law considered, it may happen that two or three pairs of planes might be chosen from the table. But this difficulty disappears if three spots on the Laue photograph are considered instead of two (see Fig. 114).

Let the angles δ_1, δ_2, and δ_3 all be measured as precisely as possible by the foregoing method, and from them let the angles η_1, η_2, and η_3 be calculated. From the table, let the pairs of planes be written down which satisfy the limitations imposed on spots L and M; M and T; and T and L. In the final selection of the pairs, spot L, for instance, must belong to a plane from which reflection is possible in accordance with the Bragg reflection law, but it must also be the common member of two pairs of planes which in their turn also satisfy this same law and inclose the interperpendicular angles η_1 and η_3. By considering each spot in turn and fitting it in with its neighbors in this way, all chance of error in choosing the planes which fit the Laue reflections is removed. The identity of the L, M, and T reflections is positively established. Fig. 114 shows the results obtained when this method is applied to the unsymmetrical Laue photograph of a silicon-steel single crystal shown in Fig. 115. The distances between the zero beam impression and the different spots and, also, the distances between the spots themselves are shown in mm. The values of the δ-angles and the generalized identities of the spots are given in Table XLII.

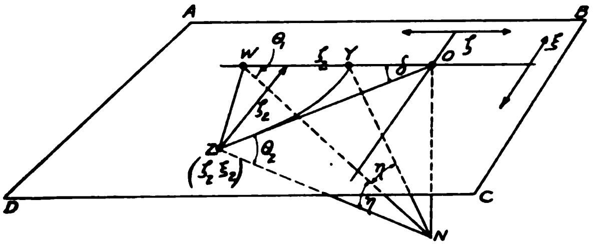


Fig. 116. Gnomonic Rotation About the Axis *WN*

TABLE XLII

VALUES OF THE δ AND θ ANGLES AND GENERALIZED IDENTITIES OF THE SPOTS IN FIG. 114

Angle	Value (Deg. Min.)	Spot	Identity
δ_1	38° 12′	L	(111)
δ_2	17° 21′	M	(110)
δ_3	53° 50′	T	(321)
θ_1	11° 7′		
θ_2	5° 45′		
θ_3	12° 55′		

Establishing the Direction and Amount of Rotation of the Crystal

After the identity of a sufficient number of spots has been established, the rotation of the specimen must be determined. With unsymmetrical photographs, the calculations are easier if each spot is treated entirely apart from its zonal relations. In certain cases perhaps the zonal relations could be employed advantageously, but in general the zone obtained will be of so complicated a relationship to the standard gnomonic projection that no advantage is secured.

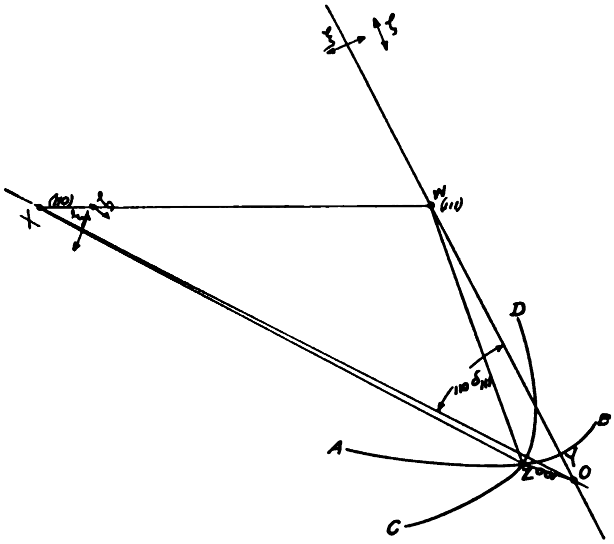


Fig. 117. Application to Actual Gnomonic Projection

In Fig. 116, let $ABCD$ represent the plane of the gnomonic projection of a Laue photograph obtained from a crystal situated at N. The common center of photograph and gnomonic projection is along the line NO. Let W be the projection of some Laue spot. Let Y be the projection of some other spot.

The angle between these two projections is denoted by η. θ_1 has its usual significance. For convenience the ζ, ξ directions are also shown. Let the crystal at N be turned about WN as an axis. The projection Y moves to Z along the path shown. The coördinates of the new projection Z are ζ_2, ξ_2. Let the new value of the Bragg angle be θ_2. The rotation is a process in which η = const. The Equations for the motion of the projection Y as the crystal is turned about the axis WN are to be derived.

The distance between the projections W and Z on the gnomonic projection can be found by considering the triangle WNZ. In this triangle, from the general Equation for triangles:

$$(WZ)^2 = (WN)^2 + (ZN)^2 - 2\ (WN)\ (ZN)\cos\eta$$

From the geometry of Fig. 116,

$$(WN) = (ON)/\sin\theta_1 \text{ and } ZN = (ON)/\sin\theta_2$$

where, (ON), the crystal-projection distance is usually denoted by R. Making these substitutions, the Equation for the length WZ becomes:

$$(WZ)^2 = \frac{R^2}{\sin^2\theta_1} + \frac{R^2}{\sin^2\theta_2} - \frac{2\,R^2\cos\eta}{\sin\theta_1\sin\theta_2} \qquad (119)$$

This Equation defines the hyperbola traced by the projection Z on the plane of the gnomonic projection as the crystal is turned about the oblique axis WN.

The coördinates ζ_2, ξ_2 of the projection can be found by reference to Fig. 116. The following Equations apply:

$$\zeta_2 = (OZ)\cos\delta \qquad \xi_2 = (OZ)\sin\delta$$

But

$$OZ = \frac{ON}{\tan\theta_2} = \frac{R}{\tan\theta_2}$$

so that

$$\zeta_2 = \frac{R\cos\delta}{\tan\theta_2} \qquad \xi_2 = \frac{R\sin\delta}{\tan\theta_2} \qquad (120)$$

Fig. 117 shows the application of this analysis to an actual gnomonic projection. The plane of the paper in Fig. 117 is the plane $ABCD$ of Fig. 116. The projections W, Y, and Z, and the zero beam impression at O correspond to these same quantities on Fig. 116. X and W represent the projections of the (110) and the (111) spots of Fig. 115 respectively. If the crystal is caused to rotate about the oblique axis WN (Fig. 116) the path of Z [the (001) projection] is the hyperbola AB: if the crystal rotates about XN (not shown on Fig. 116) the path of Z is CD. At the intersection of these hyperbolae is the position of Z when the crystal is so rotated that X and W have the positions shown on the projections. Each hyperbola is represented by an equation like (119), and the coördinates of the (001) projection at any instant may be represented by expressions like Equation (120).

TABLE XLIII

TABLE OF INTERPERPENDICULAR ANGLES INVOLVING THE CUBE FACE, BODY-CENTERED CUBIC SYSTEM

Plane-Pair	Angle in Deg. and Min.
110–100	45° 90° 135°
211–100	35° 16′ 65° 54′ 114° 6′ 144° 44′
310–100	18° 26′ 71° 34′ 90° 108° 26′ 161° 34′
111–100	54° 44′ 125° 16′
321–100	36° 42′ 57° 41′ 74° 30′ 105° 30′ 122° 19′ 143° 18′
411–100	19° 28′ 76° 22′ 103° 38′ 160° 32′
201–100	26° 34′ 63° 26′ 90° 116° 34′ 153° 26′

Let the axes of which WO and XO are the projections be called the $\{111\}$ and the $\{110\}$ axes respectively. The ζ, ξ coördinates of the (001) projection at any instant referred to the $\{111\}$ axis will be:

$$\zeta_{(111)} = \frac{R}{\tan\theta_{(001)}}\cos {}_{(111)}\delta_{(001)}$$

$$\xi_{(111)} = \frac{R}{\tan\theta_{(001)}}\sin {}_{(111)}\delta_{(001)}$$

and referred to the $\{110\}$ axis:

$$\zeta_{(110)} = \frac{R}{\tan\theta_{(001)}}\cos {}_{(110)}\delta_{(001)}$$

$$\xi_{(110)} = \frac{R}{\tan\theta_{(001)}}\sin {}_{(110)}\delta_{(001)}$$

in which the subscripts of the δ-angles show the great circles between which the δ values are considered. Let the $\{110\}$ axis be arbitrarily chosen as the standard axis. $\zeta_{(111)}$ and $\xi_{(111)}$ can be converted to this axis by means of the usual equations for changing the system of coördinates, with the following results:

$$\begin{aligned} {}_{(111)}\zeta_{(110)} &= \frac{R}{\tan\theta_{(001)}}\left(\cos {}_{(111)}\delta_{(001)}\cos {}_{(110)}\delta_{(111)} - \sin {}_{(111)}\delta_{(001)}\sin {}_{(110)}\delta_{(111)}\right) \\ &= \frac{R}{\tan\theta_{(001)}}\cos\left({}_{(111)}\delta_{(001)} + {}_{(110)}\delta_{(111)}\right) \\ {}_{(111)}\xi_{(110)} &= \frac{R}{\tan\theta_{(001)}}\left(\cos {}_{(111)}\delta_{(001)}\sin {}_{(110)}\delta_{(111)} + \sin {}_{(111)}\delta_{(001)}\cos {}_{(110)}\delta_{(111)}\right) \\ &= \frac{R}{\tan\theta_{(001)}}\sin\left({}_{(111)}\delta_{(001)} + {}_{(110)}\delta_{(111)}\right) \end{aligned}$$

in which the angle between the system of coördinates is ${}_{(110)}\delta_{(111)}$ (Fig. 117). The solution is reached when

$$\zeta_{(110)} = {}_{(111)}\zeta_{(110)} \text{ and } \xi_{(110)} = {}_{(111)}\xi_{(110)}$$

or, as can be readily shown, when

$${}_{(110)}\delta_{(001)} = {}_{(111)}\delta_{(001)} + {}_{(110)}\delta_{(111)} \qquad (121)$$

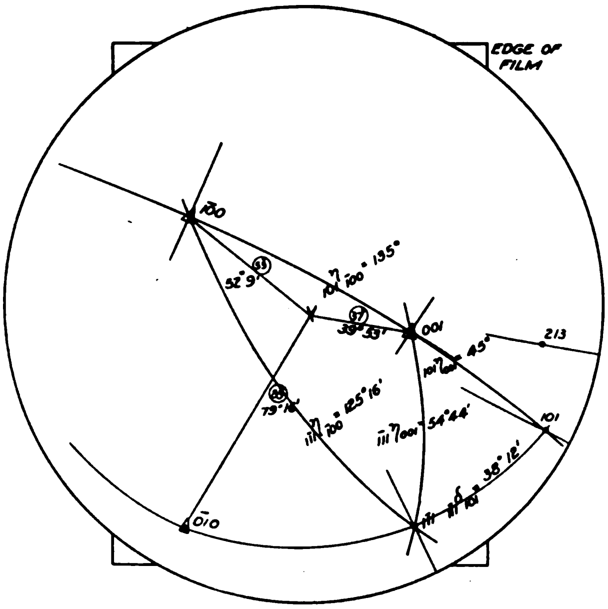

EDGE OF FILM
$\bar{1}00$
001
213
101
$0\bar{1}0$
$\bar{1}11$
52°9'
39°53'
79°16'
$_{101}\eta_{\bar{1}00}$ = 135°
$_{101}\eta_{001}$ = 45°
$_{\bar{1}11}\eta_{\bar{1}00}$ = 125°16'
$_{\bar{1}11}\eta_{001}$ = 54°44'
$_{\bar{1}11}\delta_{101}$ = 38°12'

Fig. 118. Stereographic Projection of the Crystal of Fig. 115

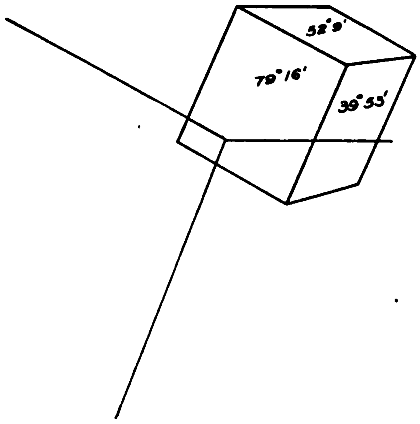


Fig. 120. Perspective View of Cube in the Orientation of Fig. 118

in which $_{(110)}\delta_{(111)}$ is obtained from the Laue photograph by the use of Equation (118). The values of $_{(110)}\delta_{(001)}$ and of $_{(111)}\delta_{(001)}$ may be calculated from this same equation, using the value of η from Table XLIII, the value of θ_1 obtained from the Laue photograph, and an assumed value of θ_2. In the present case, the equations used will be:

$$\left.\begin{aligned} \cos_{(110)}\delta_{(001)} &= \frac{\cos_{(110)}\eta_{(001)} - \sin\theta_{(110)}\sin\theta_{(001)}}{\cos\theta_{(110)}\cos\theta_{(001)}} \\ \cos_{(111)}\delta_{(001)} &= \frac{\cos_{(111)}\eta_{(001)} - \sin\theta_{(111)}\sin\theta_{(001)}}{\cos\theta_{(111)}\cos\theta_{(001)}} \end{aligned}\right\} \quad (118a)$$

and Equation (121).

Equations (118a) are probably best solved by a method of approximation. Different values of $\theta_{(001)}$ are substituted until a value is found which satisfies Equation (121). In order that an idea may be formed as to the probable size of $\theta_{(001)}$, it is advisable that a small stereographic projection of the Laue photograph be made (Part XIV). This will serve as a guide to determine which values of η and θ to use in the preceding equations, since there are usually more than one value of the inter-perpendicular angles between any generalized pair of planes, and the geometrical relations in the given orientation are not always visualized easily.

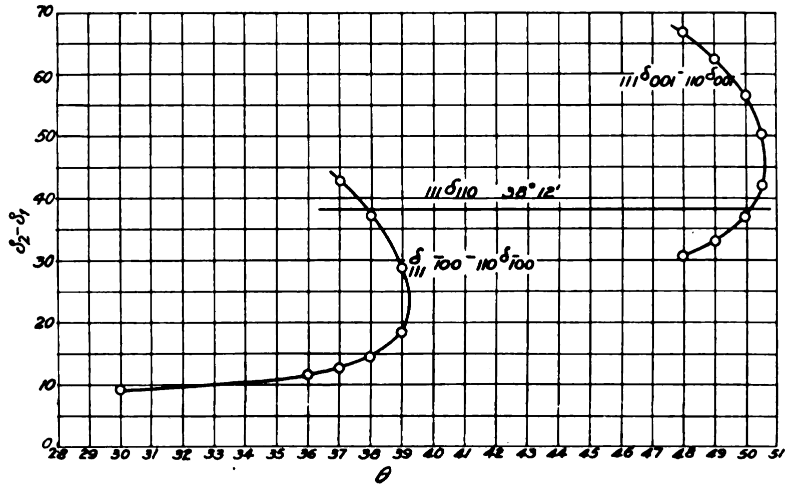


Fig. 119. Graphical Solution for θ_{001} and θ_{100}

Application to the Actual Determination of the Orientation of a Crystal

Fig. 118 shows the small stereographic projection of the Laue photograph of Fig. 115 with the indices assigned to the three key-spots, and with the positions of the three face-perpendiculars located. The values in the circles represent the values of $90-\theta$ for each of the face perpendiculars as closely as they could be read from the stereographic rotation net (Part XII) used for plotting Fig. 118. The η-values existing between the different plane perpendiculars are also noted. These values were obtained by measuring off the approximate values on the stereographic projection and then obtaining from Table XLIII the values which fitted these approximate values the best. The

TABLE XLIV

DATA FOR DETERMINING THE ORIENTATION OF THE CRYSTAL OF FIG. 115

Values of $_{(111)}\delta_{(001)} - _{(110)}\delta_{(001)}$ obtained for different $\theta_{(001)}$ values.

$\theta_{(001)}$ (deg.)	$_{(111)}\delta_{(001)} - _{(110)}\delta_{((001)}$ deg.)	
48°	30° 28′	66° 45′
49°	33° 12′	62° 32′
50°	37° 19′	56° 47′
50° 7′	38° 11′	
50° 30′	42° 6′	50° 15′

Values of $_{(111)}\delta_{(\bar{1}00)} - _{(110)}\delta_{(\bar{1}10)}$ obtained for different $\theta_{(\bar{1}00)}$ values.

$\theta_{(\bar{1}00)}$ (deg.)	$_{(111)}\delta_{(\bar{1}00)} - _{(110)}\delta_{(\bar{1}00)}$ (deg.)	
37°	12° 44′	42° 48′
37° 51′		38° 12′
38°	14° 30′	37° 8′
39°	18° 30′	28° 44′

Value of $\theta_{(0\bar{1}0)}$ calculated from Equation (114). Part XV, 10° 44′.

Values of $90-\theta$ for the face perpendiculars.

Plane	$90-\theta$ (deg.)
001	39° 53′
$\bar{1}00$	52° 9′
$0\bar{1}0$	79° 16′

appropriate θ-values from Table XLII were used. By substituting in Equations (118a) values of θ in the region indicated by the measurements on the stereographic projection, the values for the difference between the δ-angles tabulated in Table XLIV were obtained. By plotting these values as shown in Fig. 119, the points at which the curves intersected the line $_{(111)}\delta_{(110)} = 38°\ 12'$ (Table XLII) were obtained. These points were the more precise values of the θ-angles desired. By calculation it was possible to verify these points as shown in Table XLIV.

In order to obtain the value of θ for the $(0\bar{1}0)$ plane, use was made of Equation (114) (Part XV). The value obtained is shown in Table XLIV.

The values thus obtained are the complements of the angles desired. The $(90-\theta)$ angles are included in Table XLIV. These represent the angles formed between the perpendiculars to the cube faces and the path of the x-ray beam, which in this case was perpendicular to the face of the specimen. The orientation thus obtained for the unit cube is shown in Fig. 120, with the values of the $(90-\theta)$ angles marked on the appropriate faces.

(To be Continued)

Lightning Tests Made on Commercial Transformers

For the first time in electrical history full lightning tests were made on August 8 and again on August 12 on commercial transformers. These transformers were built at the Pittsfield Works of the General Electric Company for operation on the Fifteen-Mile Falls 220-kv. transmission line of the New England Power Company, and the tests were conducted under the direction of F. W. Peek, Jr., in charge of the high-voltage laboratory of the Company.

Three-million-volt lightning waves, used in making the tests, were conducted from the laboratory over a short line to the testing department and repeatedly applied to the 13,000-kv-a. transformers immediately after the commercial tests were completed. The transmission-line insulation arrangement was made to compare with operating conditions—fifteen shielded units on the main line and fourteen units at the transformer. The lightning waves were of a type to produce the severest stresses and covered a range of time varying from one-half of a microsecond front to 80 microseconds tail. It was found impossible to break the transformers down.

The transformers were of the non-resonating type described by K. K. Palueff in his paper entitled "Effect of Transient Voltages on Power Transformer Design," presented at the mid-winter A.I.E.E. convention in January, 1929. They were designed for the standard A.I.E.E. 3.46 test.

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

Alternators

Flywheel-Alternators for Medium-Sized Diesel Sets. J. Hein.
AEG Progress, May-June, 1930; v. 6, pp. 158-164.

Electric Arc

Cathode Energy of the Iron Arc. Gilbert E. Doan.
A.I.E.E. Jour., June, 1930; v. 49, pp. 453-457.
(Pertains to the arc used for welding. Abridgment.)

Electric Lighting—Display Purposes

Building Prosperity Avenue. H. H. Magdsick.
Illum. Engng. Soc. Trans., May, 1930; v. 25, pp. 451-460.
(Various kinds of display lighting for the exteriors of large buildings.)

Generators, D. C.

Voltage Irregularities in D-C. Generators. J. T. Fetsch.
A.I.E.E. Jour., June, 1930; v. 49, pp. 436-440.
(Abridgment.)

Lightning

Surges and Over-Voltage Phenomena on Transmission Lines Due to Lightning. H. Norinder.
I.E.E. Jour., May, 1930; v. 68, pp. 525-533.
(A review of recent developments.)

Measuring Instruments

Determination of Generator Speed and Retardation During Loss Measurements. O. E. Charlton and W. D. Ketchum.
A.I.E.E. Jour., June, 1930; v. 49, pp. 428-431.
(The construction and use of a chronograph for obtaining speed-time curves when testing generators. Abridgment.)

Oscillographs

Method of Measuring Cathode Ray Oscillograph Figures. Raymond M. Wilmotte.
Franklin Inst. Jour., June, 1930; v. 209, pp. 809-813.

Power Plants, Electric

Naval Electrical Power in Commercial Use—U.S.S. "Lexington" Relieves Tacoma Power Shortage. H. L. White.
Am. Soc. Nav. Engrs. Jour., May, 1930; v. 42, pp. 311-315.

Radio Industry—Laws

Radio Engineer and the Law. Paul M. Segal.
Inst. Radio Engrs. Proc., June, 1930; v. 18, pp. 1038-1043.

Signalling

Luminous Traffic Signals. T. Austin.
Illum. Engr., June, 1930; v. 23, pp. 142-148.
(Paper presented before Illuminating Engineering Society, London.)

Transformers—Testing

Iron Loss Measurements on Three-Phase, Three-Limb, Core Type Transformers. R. M. W. Grant.
Wld. Power, June, 1930; v. 13, pp. 552, 557-560.

Welding

Strength and Design of Fusion Welds for Unfired Pressure Vessels. L. W. Schuster.
Am. Weld. Soc. Jour., May, 1930; v. 9, pp. 18-64.
(From an extensive paper read before the I. M. E.)

NEW BOOKS

(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.)

Aluminum Industry. Vol. 1: Aluminum and Its Production; Vol .2: Aluminum Products and Their Fabrication. Junius D. Edwards, Francis C. Frary, and Zay Jeffries. 358 pp. and 870 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $12.00 (2 vols.).

(An extensive work prepared with the collaboration of other experts who, as in the case of the major authors, are all on the staff of the Aluminum Company of America. This coöperative effort seems to have produced what the authors hoped for, viz., "a broad and instructive picture of the aluminum industry." Volume one provides, in nine chapters, a history of the discovery of aluminum and the development of the industry, a discussion of the ores of aluminum and their mining and refining, and an account of the production of pure alumina and of metallic aluminum. The much larger second volume devotes twenty-three chapters to a treatment of the properties of aluminum and its alloys, the fabrication of aluminum products, and the industrial uses of aluminum. The authors say: "The available books are either out of date or do not contain authentic information on many of the subjects in which the greatest interest is being shown. It is to meet this need that the present volumes were prepared . . . This book has been written with a view of interesting not only the specialist but also the searcher for general information on the properties and uses of aluminum." The treatment is ample and the arrangement is orderly. Bibliographic footnotes, with special attention to patent references, are freely interspersed, and lists of collateral reading are provided where they would seem of value. A large number of well-executed drawings and photographs, together with numerous tables of data, contribute to the usefulness of the text. Adequate name and subject indexes are provided for each volume.)

Bearing Metals and Bearings. W. M. Corse. 383 pp., 1930, N. Y., Chemical Catalog Co. $7.00.

Electrical Distribution Engineering. Howard P. Seelye. 710 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $6.00.

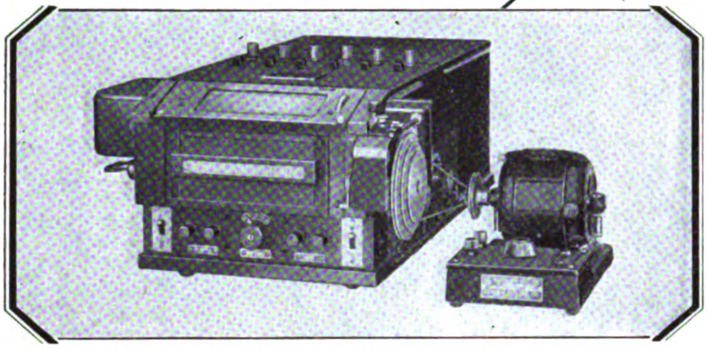
Entwurf und Bau von Schaltanlagen für Drehstrom-Kraftwerke. Johann Waltjen. 268 pp., 1929, Berlin, Julius Springer. 39 R. M.

(A text intended for students and designers concerned with the fundamentals underlying the design and construction of switchgear for modern alternating-current power systems. The book is divided into three parts, of which the first deals briefly with the general principles of layout of a switchgear installation and with the various transients—such as short circuits, overvoltages, excess currents, and methods of protection against them. The second part discusses the various switchgear apparatus, including the measuring instruments and their transformers. Short chapters are also devoted to the power transformer and its cooling problems, as well as to the transmission line. In the third part the author gives methods of practical design and layout, with numerous examples.)

Der Erdschluss und Seine Bekampfung. G. Oberdorfer. 165 pp., 1930, Berlin, Julius Springer. 12.50 R.M. (paper.)

(This small book on grounds and their prevention and suppression is devoted entirely to a discussion of grounds as they occur in high-tension networks. The author gives a mathematical treatment of the problems involved, and then presents the theory and practice of locating, preventing or eliminating such faults. A list of important German patents pertaining to grounds, a five-page bibliography, and a subject index complete the volume.)

The New



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General Electric six-element oscillograph

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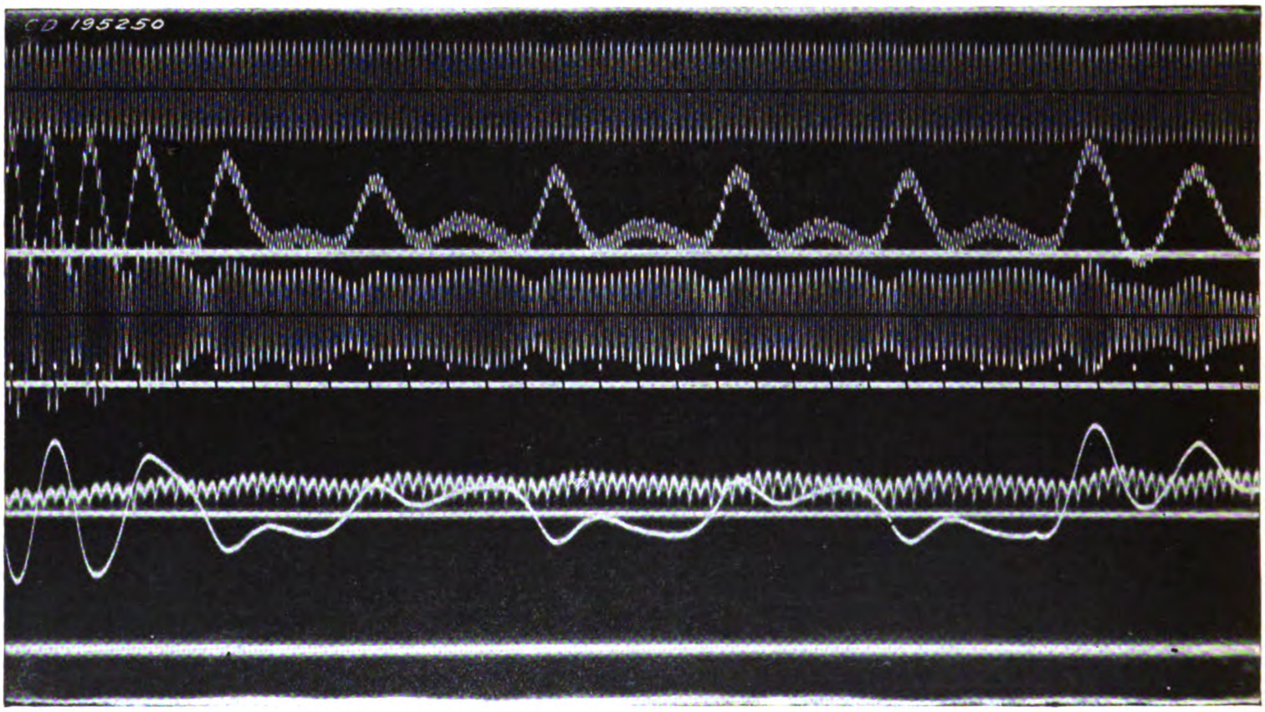

Section of original film 10 ft. long. The film used is nearly 6 in. wide

For a complete description of General Electric permanent-magnet oscillographs, ask for Bulletin GEA-1209A. It describes also new two-element oscillographs of unique design.

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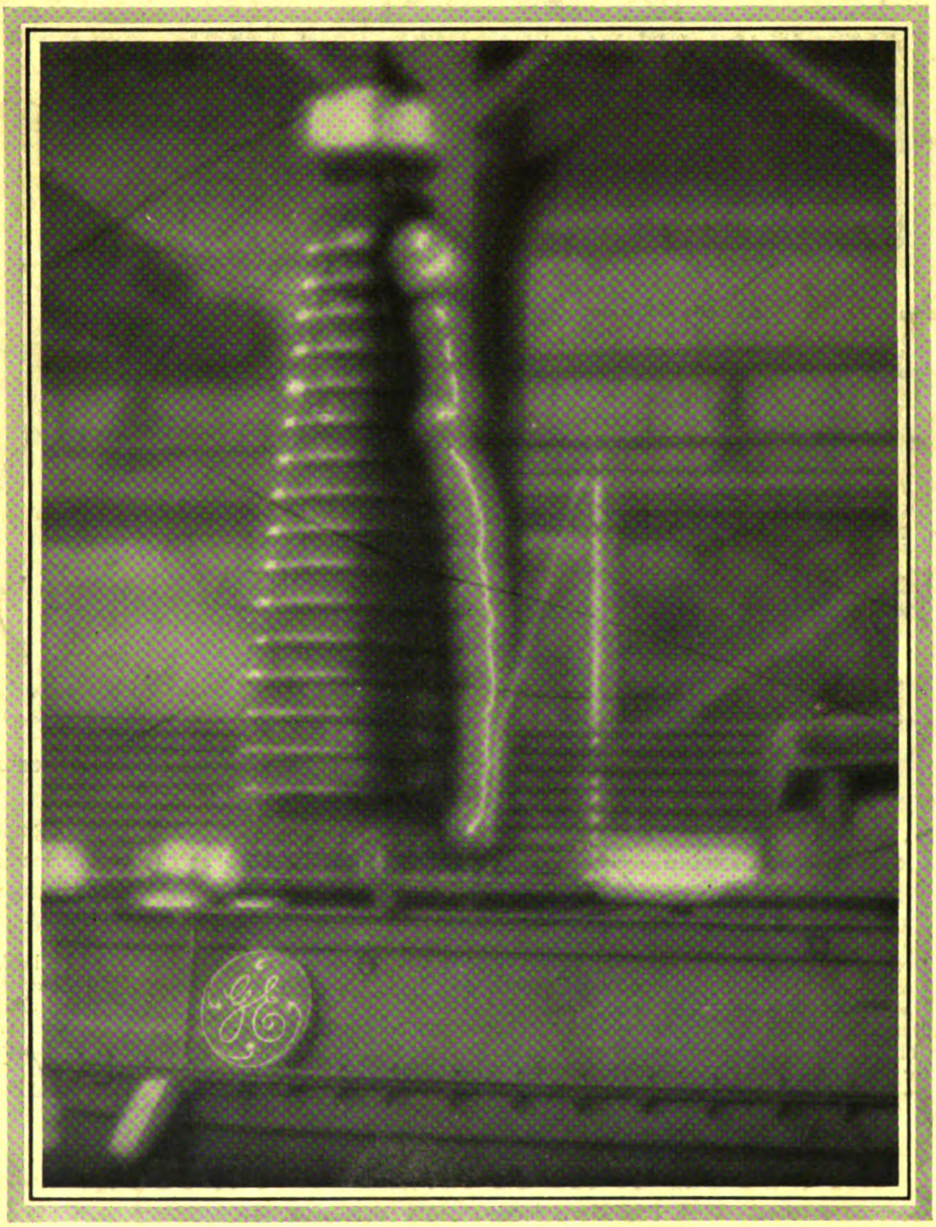
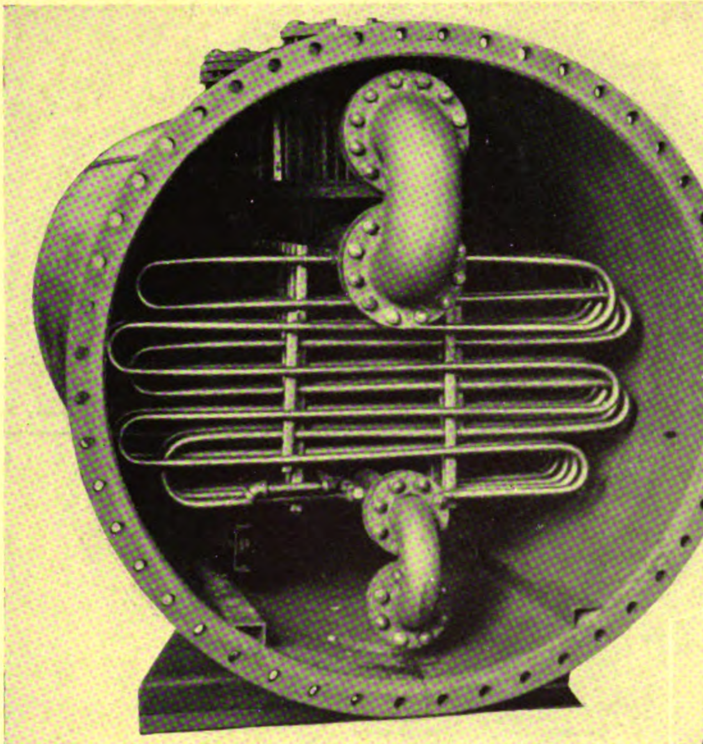
VOL. 33, NO. 10 OCTOBER, 1930



TRANSFORMER WITHSTANDS LIGHTNING

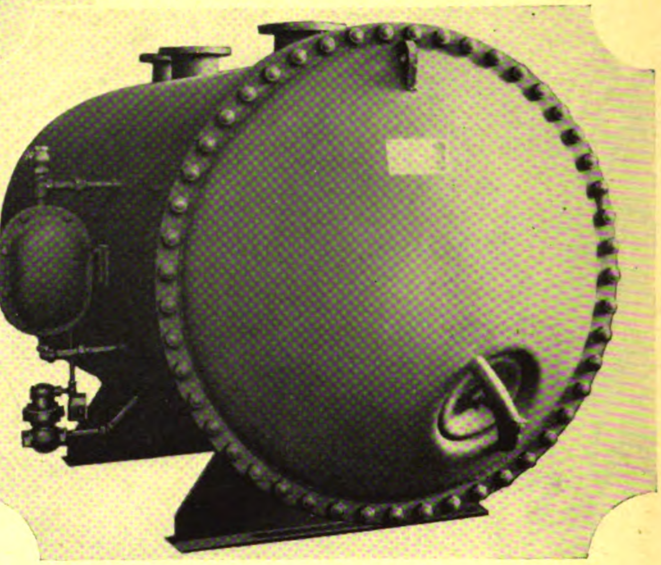
One of the artificial lightning discharges that took place over the bushing on the recent occasion of the first lightning test of a commercial transformer. (*See p. 592*)

In This Issue: *Tests of Welded Joints* *New Stroboscope* *Non-resonating Transformer* *Vacuum Tube Applications* *Emergency Substation* *Modern Railroad Power System* *New Method for Starting Motors* *Switchgear* *Brazing* *Elevator Power Calculations*



Foster Wheeler evaporator showing tube bundle and steam purifier within the shell. The staggered arrangement of the coils extending the width of the shell, effectively distributes the heating surface throughout the body of water.

(Right) Completed Foster Wheeler evaporator assembled at shops for testing, before shipment. The balanced feed valve with float control, shown on left of shell, regulates the water level in the evaporator.



FW

High-Pressure Evaporators

Foster Wheeler evaporators, of the type illustrated, are used for high-pressure operation. They are designed with horizontal shells and submerged coils.

Most effective thermal circulation in the evaporator is assured by staggering the coils which extend across the width of the shell. Unusually large releasing area results in low velocity of the vapors and minimum entrainment of moisture.

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Firestone Tire & Rubber Co.	Los Angeles, Calif.
Ford Motor Company	Detroit, Michigan
Kansas City Power & Light Co.	Kansas City, Missouri
New England Public Service Co.	Augusta, Maine
N. J. Power & Light Co.	Holland, N. J.
North Western Public Service Co.	Aberdeen, S. D. Mitchell, S. D.
Paraffine Companies	Emeryville, Calif.
Super Power Co. of Ill.	Powerton, Ill.
Waukegan Generating Company	Waukegan, Illinois
Wisconsin Power & Light Co.	Madison, Wisconsin

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SCHENECTADY, NEW YORK

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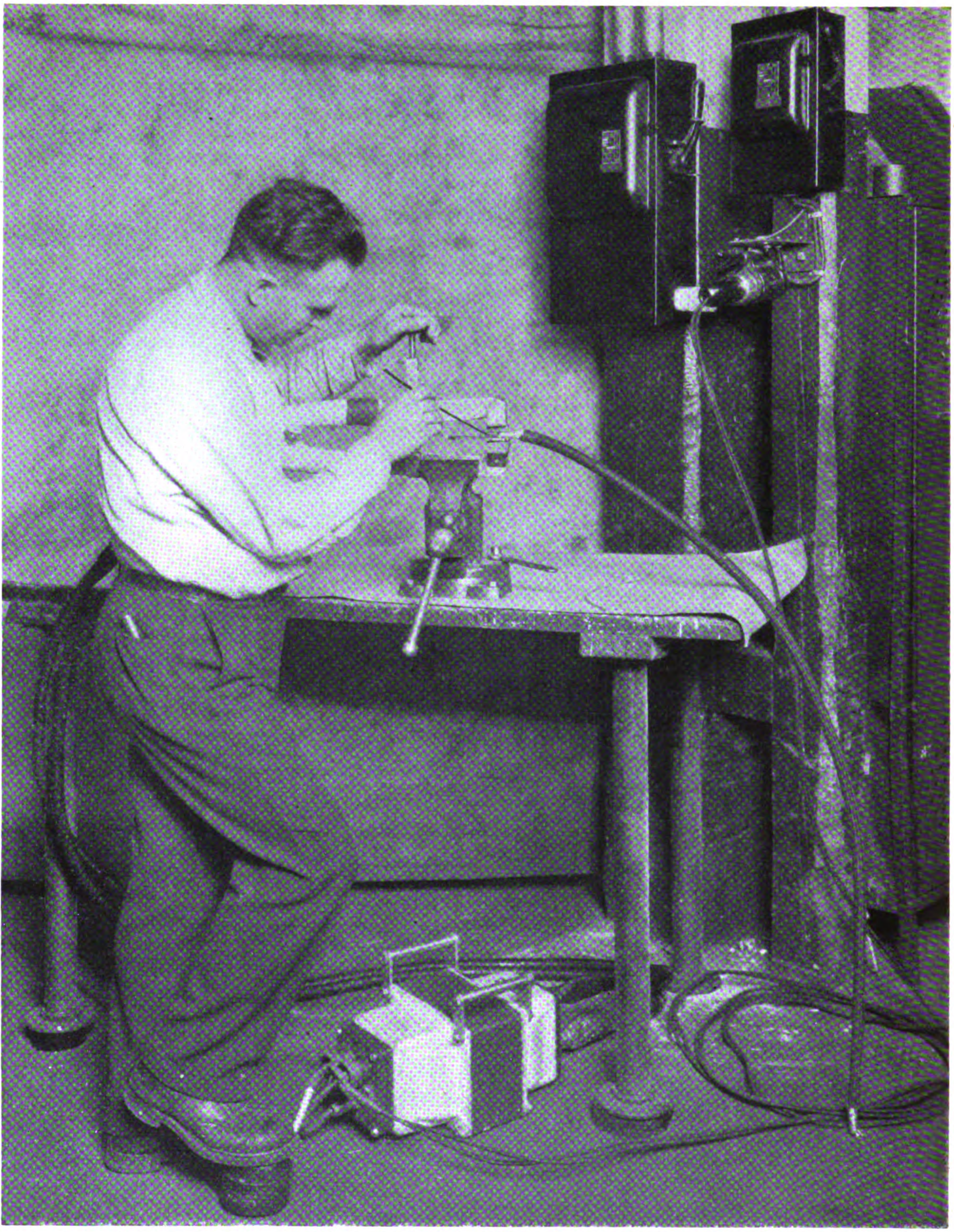
monthly by *INDUSTRIAL ARTS INDEX*, and weekly and annually by *ENGINEERING INDEX*: and abstracted monthly by *SCIENCE ABSTRACTS*



ELECTRIC RESISTANCE BRAZING

Newly developed equipment for electric brazing by the resistance method. Energy drawn from an ordinary commercial supply is suitably transformed and on passing through carbon blocks each side of the joint to be brazed produces the requisite temperature for the process. (*See P. 568*)

GENERAL ELECTRIC REVIEW

Vol. 33 October, 1930 No. 10

A TRIBUTE

"For the earth bringeth forth fruit of herself; first the blade, then the ear; after that, the full corn in the ear."

The children of the earth not only reproduce after their kind, like a grain of mustard seed, but with that Heaven-sent gift of imagination, sow thoughts and works which ripen into a richer harvest. First the inquisitive thought, then the experimental research, then the discovery of Natural Law, and after that, the harvesting of the fruits of discovery.

Volta, Faraday, and their inestimable peers in many lands sowed the seeds of the electrical industry.

An inquisitive old lady and Mr. Gladstone both, in these words, inquired of Faraday the value of his discovery. "But, Professor Faraday, even if the effect you explain is obtained, what is the use of it?" To the first he replied, "Madam, will you tell me the use of a new-born child?" To the Prime Minister of England he said, "Why, Sir, there is every probability that you will soon be able to tax it."

We have reaped an ever-increasing harvest each year from the fruits of the imagination of our early pioneers in scientific research. The electrical industry has grown beyond the imagination of even imaginative men, it has rearranged our civilization, and transformed the world with a new order of things; it has been taxed and taxed and taxed; it has rendered a revenue exceeding the combined wealth of many nations in the era when it started to germinate.

We are justly proud of the part the General Electric Company has played in bringing about this new order of things. If we trace our Company to its beginning, we find it the same age as the Electrical Industry, both are about fifty years old.

A biblical phrase accounts the span of a man's life as threescore years and ten, but we usually reckon three generations to a century; so it is not surprising that the ranks of those whose thoughts and works have made us what we are today, are getting thinner and ever thinner year by year.

We are specially mindful of those wonderful pioneers in our own G. E. Family at the present time, because some of the dearest and the best are retiring now. Therefore, we take this opportunity to pay a tribute to you all. To those who have passed beyond; to those who have retired in the past; to those who now retire, and to those about to retire in the immediate future.

We do not limit our tribute to the chiefs alone; we wish to include the laborers—the hands to others' brains, whose often uncongenial tasks helped to carry others' work to fruition; that great host of machinists and mechanics whose skill and work we admire and respect so much as having fashioned and perfected the children of imaginative brains; the engineers, the Creator's agents; the commercial men—those who brought the grist to the mill; the experimental researcher, whose imagination led to discovery; and the executives, who guided us all.

In paying our tribute to you, we wish to acknowledge that it was your work, tempered with a knowledge that increased each year, and leavened by an ever-abiding spirit of loyalty and constant service, that enabled mankind to reap a richer harvest each year and will enable future generations to sow, in a better-prepared soil, and reap increasing abundance.

We feel that it would be an offense to dehumanize mankind and always to glorify the names of Science, Production, Dividends, and Pension Systems, etc.—forgetful of those intensely human men who sweated mentally and physically to give us these blessings.

So first, we congratulate you one and all on having lived such useful lives, and, very specially, on the thrilling joy you have had in accomplishing great and ever greater things. And then we pay our homage to your ceaseless work; to your loyalty; to the inspiration with which you inspired others; and to the congenial atmosphere and spirit of coöperation and fraternity that you created and have left us as our priceless heritage.

Some of you can never be paid in full; except in the consciousness that a man is known by his works, in the certainty that the children of your brains will always grow, and in the knowledge that we shall always remember, respect, and love you.

J. R. H.

Modernizing the D-c. Power System of the Northwestern Pacific Railroad

By E. H. SCHAUBEL

Superintendent of Electrical Activities, Northwestern Pacific Railroad Company

The transportation companies that years ago took advantage of electrification are now one by one taking advantage of re-electrification with the decidedly superior equipment of today. As described in this article on the d-c. power supply of the Northwestern Pacific Railroad, new converting units and automatic switching equipment take the place of prime mover units, some of which have faithfully served their purpose for 26 years.—EDITOR.

THE Northwestern Pacific Railroad Company, as part of the Redwood Empire Route, operates a combination ferry and interurban electric train service between San Francisco and points in Marin County (Calif.). This electric service was inaugurated in September, 1903.

The Marin ferry terminal is located at Sausalito, and from this point electric train service extends northward, linking Sausalito with Mill Valley, San Anselmo, San Rafael, and other small communities. Fig. 1 is a map showing the electrified section. The ferry boats are essentially for passenger service, although automobiles also are carried. The bulk of the passenger traffic is made up of commuters who have their places of business in San Francisco and their homes in the beautiful country situated to the north across the Golden Gate of San Francisco Bay. On week days there are the usual heavy morning and evening traffic peaks, but the heaviest peaks occur on Sundays because Marin country is a natural playground that attracts thousands of pleasure seekers who spend the day roaming over the wooded slopes of Mt. Tamalpais and hiking to the seashore over the famous Dipsea Trail or over other trails in the surrounding canyons.

The development of the power system of the Railroad took place as follows: In 1903, the Alto Powerhouse was built. Its equipment consisted of one 400-kw. 600-volt Stanley generator, direct connected to a tandem-compound Corliss engine and two similar generators driven through a rope drive by one 1000-hp. engine. A coupling arrangement was provided whereby these two generators could be driven by Stanley inductor-type motors. Power for these motors was supplied at 60,000 volts by the California Gas & Electric Company (now Pacific Gas & Electric Company). A 2000-amp-hr. 600-volt storage battery was also a part of the power-plant equipment.

Shortly after the completion of the Alto Powerhouse, the power demands necessitated the temporary installation of a 250-kw. steam-driven generator at San Rafael pending the installation of a 2500-amp-hr. storage battery at San Anselmo. In 1904, the storage battery at Alto was moved to the Sausalito Shops and its capacity increased to 2500-amp-hr. In 1906, a 1000-kw. turbine-generator was added to the Alto Powerhouse. Two years later the battery at San Anselmo was replaced by two 500-kw. motor-generator sets, and in 1912 a third 500-kw. unit was added. The storage battery at the Sausalito Terminal rapidly deteriorated under the heavy load conditions and in 1911 it was removed. At this time the feeder cable between Alto and the Sausalito Terminal was increased. In 1912, a 1000-kw. motor-generator set was installed at the Alto Powerhouse.

In 1928, Edward H. Maggard became president and general manager of this property, and under his management a general rehabilitation of the interurban system was inaugurated. Along with improvements in track, new steel rolling equipment, new stations and concrete platforms, the adoption of a new public-relations policy, improvement in the power system was desired. An engineering study resulted in the rearrangement of facilities and the construction of three completely automatic substations to meet the demand for better service. The elimination of operators at the San Anselmo Substation and the retirement of the steam equipment at Alto Powerhouse, with its operating forces, made possible the operating economies necessary to justify the capital expenditures for the new equipment.

One substation was built at Pine, one mile north of the Sausalito Terminal, and a 1500-kw. synchronous converter with complete automatic switching equipment installed. A second new substation was constructed at Baltimore Park, midway between Alto and San Anselmo, and the 1000-kw. motor-generator set, formerly at Alto Powerhouse, has been installed and equipped with complete automatic switching equipment. Two new 1000-kw. synchronous converters with complete automatic switching equipment have been installed in the San Anselmo Substation. Three 500-kw. motor-generator sets, formerly at San Anselmo, were installed at Alto with manual switching equipment. These are in addition to the two 400-kw. motor-generator sets already installed.

Three-phase 60-cycle power for all substations is purchased from the Pacific Gas & Electric Company.

This rehabilitation of the direct-current power system has made it possible to abandon the generating plant at Alto and this plant is being removed. Fig. 2 shows the arrangement of the power and distribution system.

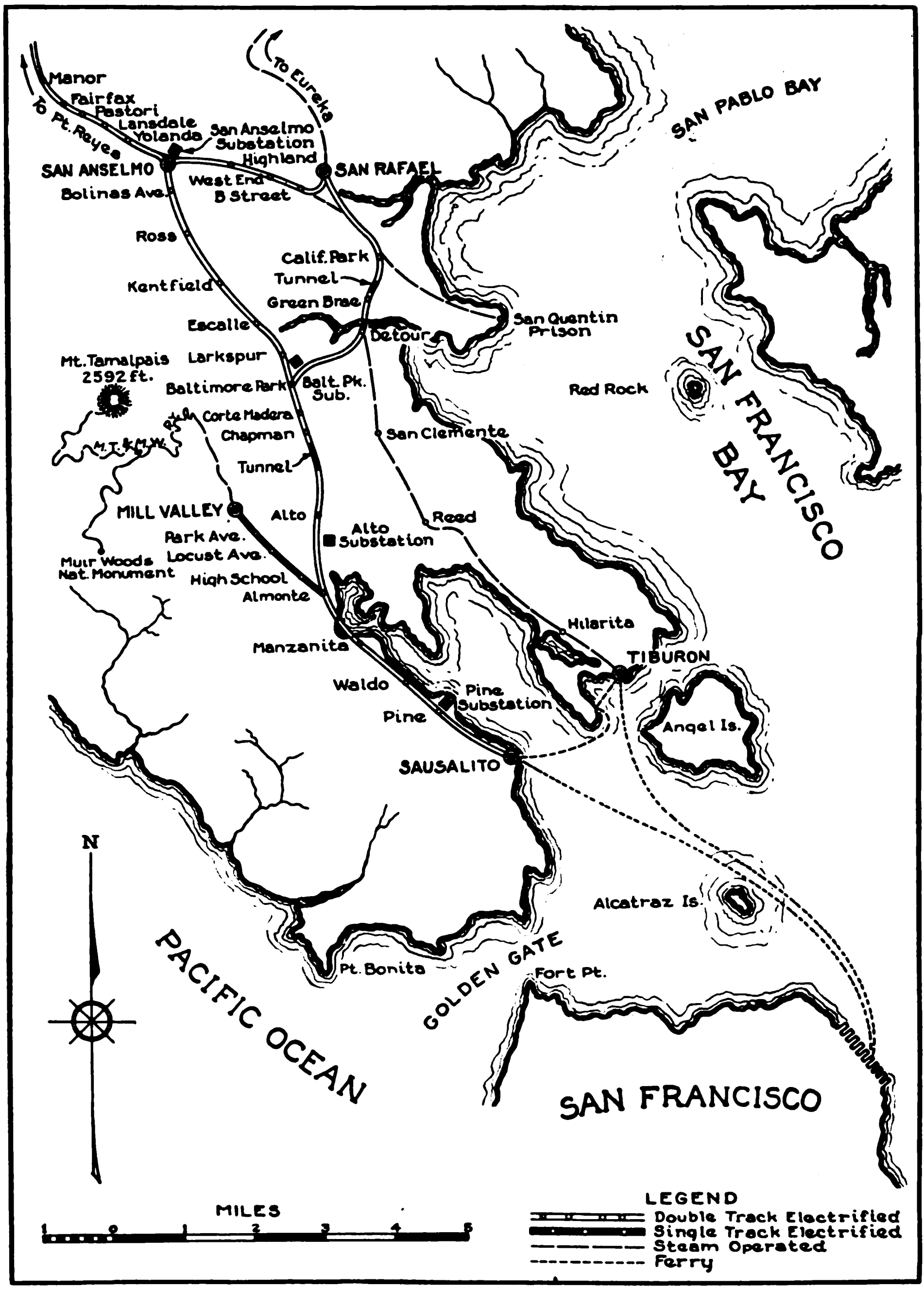

To Pt. Reyes
Manor
Fairfax
Pastori
Lansdale
Yolanda
San Anselmo Substation
To Eureka
SAN ANSELMO
Highland
SAN RAFAEL
West End
B Street
Bolinas Ave.
Ross
Calif. Park
Tunnel
Kentfield
Green Brae
Escalle
Detour
San Quentin Prison
SAN PABLO BAY
Mt. Tamalpais 2592 ft.
Larkspur
Baltimore Park
Balt. Pk. Sub.
Red Rock
SAN FRANCISCO BAY
Corte Madera
M.T.&M.W.
Chapman
San Clemente
Tunnel
MILL VALLEY
Alto
Alto Substation
Reed
Park Ave.
Locust Ave.
Muir Woods Nat. Monument
High School
Almonte
Hilarita
Manzanita
TIBURON
Waldo
Pine Substation
Pine
Angel Is.
SAUSALITO
N
Alcatraz Is.
PACIFIC OCEAN
Pt. Bonita
GOLDEN GATE
Fort Pt.
SAN FRANCISCO
MILES
1 0 1 2 3 4 5
LEGEND
Double Track Electrified
Single Track Electrified
Steam Operated
Ferry

Fig. 1. Map of the Interurban Lines of the Northwestern Pacific Railroad Company

The new substation buildings at Pine and Baltimore Park are of reinforced concrete. The latter was made sound-proof by double-wall construction; and to reduce vibration noises, the machine was set on a concrete foundation separated from the building by cork pads. Considerable attention was given to the architectural features, and as a result the new buildings fit in pleasingly with their surroundings. Careful study was also given to the matter of proper and adequate ventilation. The interior of San Anselmo Substation has been suitably remodeled. This building and the one at Alto are of substantial brick construction.

The equipment at Pine Substation, a shunt-wound synchronous converter, was chosen because of the station's proximity to the Sausalito Terminal. On the peak evening trips there are five trains leaving the terminal at very short intervals after the ferry boat docks, the total number of cars for the five trains being 28. At the same time there are five trains with a total of 10 cars approaching the terminal. In other words, there are 38 cars within the zone of the Pine Substation at one time. The average weight per car is 33 tons. This creates a very heavy demand upon the machine and the shunt characteristics were found to be suitable for such conditions. The converter transformer is located outside the building and steps down from 11,000 volts three phase to 445 volts six phase.

Over the light-load period, the machine is started by load demand as evidenced by low voltage on the bus, and is shut down when the load demand disappears. Over the peak-load period, continuous operation is effected by means of a time switch. From 1:30 a.m. to 6:00 a.m., the machine is kept out of operation by the time switch. Y-delta starting on the high-voltage side of the transformer is used so that the heavy cables are run direct from the low-tension side of the transformer to the converter rings without a break. The 11,000-volt line oil circuit breaker, and the starting and running oil circuit breakers are operated by motor mechanisms from the 220-volt a-c. control bus. The automatic equipment includes the full set of relays and devices required for the complete automatic operation and protection of the apparatus, and provisions are included for the maintenance of service under all conditions. The converter is protected by a 3000-amp. high-speed breaker in the negative with cushioning resistor. A two-step load-limiting resistor is connected in the positive, rated 3750 amp. for five minutes. The output is carried directly to the third rail through a single 3000-amp. feeder breaker of the automatic-reclosing and load-discriminating type.

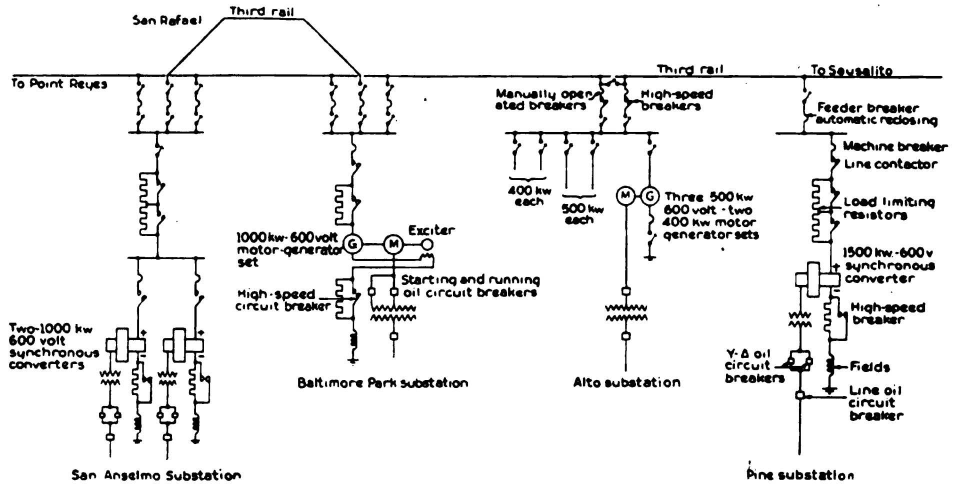

San Rafael
Third rail
To Point Reyes
1000 kw-600 volt motor-generator set
Exciter
G
M
Starting and running oil circuit breakers
High-speed circuit breaker
Two-1000 kw 600 volt synchronous converters
San Anselmo Substation
Baltimore Park substation
Third rail
To Sausalito
Manually operated breakers
High-speed breakers
400 kw each
500 kw each
Three 500 kw 600 volt - two 400 kw motor generator sets
Alto substation
Feeder breaker automatic reclosing
Machine breaker
Line contactor
Load limiting resistors
1500 kw.-600 v synchronous converter
High-speed breaker
Y-Δ oil circuit breakers
Fields
Line oil circuit breaker
Pine substation

Fig. 2. Diagram of the Power Supply and the Distribution System

At San Anselmo, the two 1000-kw. converters are compound-wound (as it was considered feasible and desirable to maintain the third-rail voltage at this point at a constant value) and are equipped with full-automatic switching equipment. The arrangement here is essentially the same as at Pine, except that relays have been included to cover the operation of two machines. A throw-over control switch is also provided for making either machine the leading machine to come on the line. The trailing machine comes on after the load becomes too heavy for one machine, and it shuts down when the load drops within the capacity of a single machine. Emergency starting of the trailing machine is also provided for in case the leading unit is held out of service. The load-limiting, resistor has a continuous capacity of 2500 amp. and the switch arrangement is such that this resistor cannot be cut in the circuit when both machines are running, as the combined capacity of the two machines is sufficient to meet all load demands. There are three 2000-amp. automatic reclosing feeders at San Anselmo feeding from a common bus to three separate sections of third rail.

At Baltimore Park is the 1000-kw. synchronous motor-generator set that was moved from Alto. Complete automatic switching equipment is installed similar in most respects to that installed at the Pine and San Anselmo stations except for difference incident to the control of a motor-generator set. The power transformer steps down from 11,000 volts to 4400 volts and the synchronous motor is started from 50 per cent starting taps. One step of load-limiting resistance is used, having a capacity of 2500 amp. for five minutes. This equipment has a high-speed breaker in the negative. The exciter for the synchronous motor is compounded by shunting a portion of the 1000-kw. generator output through a series field, which automatically strengthens the motor field as the load is increased. Three 2000-amp., 600-volt reclosing feeders are installed.

Manual operation will be continued at Alto Substation. The two feeders out of this station are equipped with 3000-amp. high-speed circuit breakers which when tripped by overload cause the line breakers to open. As soon as the latter breakers open, the high-speed breakers immediately reclose. The operator, notified by an alarm, recloses the line breakers manually. This substation also serves as a high-tension line switching and transformer station of the Pacific Gas & Electric Company. The incoming power service is at 60,000 volts; five 11,000-volt lines originate at this substation, two of which serve the railroad substations at Pine and Baltimore Park. These latter lines have switching equipment so arranged at Alto that they may be served by either of two transformer banks. There are also two 60,000-volt sources to serve either of these two banks of step-down transformers.

Owing to the proximity of interlocking towers, a simple, comprehensive, and inexpensive system of remote control with indications has been installed at San Anselmo and Baltimore Park. A similar

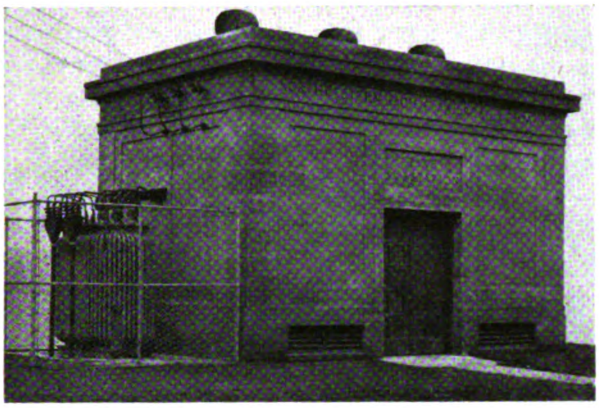


Fig. 3. The 1500-kw. Automatic Substation at Pine

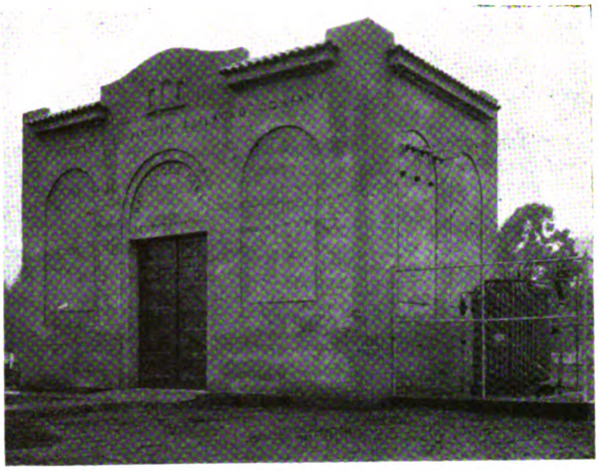


Fig. 6. The 1000-kw. Automatic Substation at Baltimore Park

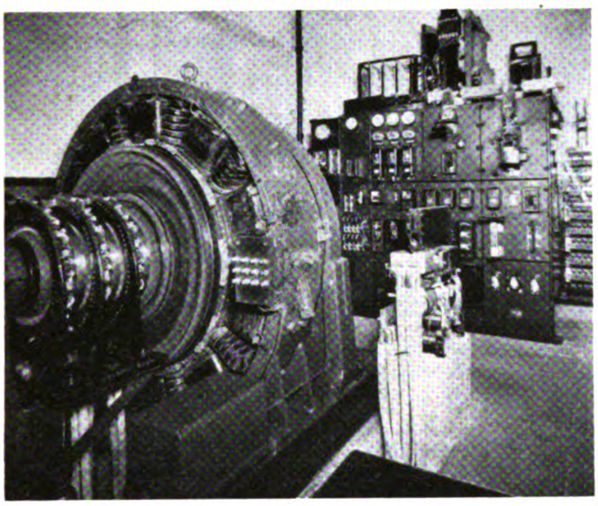


Fig. 4. The A-c. End of the 1500-kw. Synchronous Converter and the Automatic Control Equipment in the Pine Substation

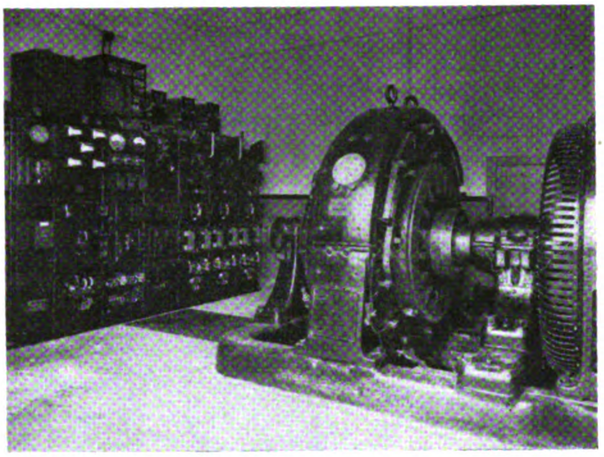


Fig. 7. The Motor-generator Set That Formerly was Manually Operated, and is now Located as Shown with Its Automatic Control Equipment in the Baltimore Park Substation

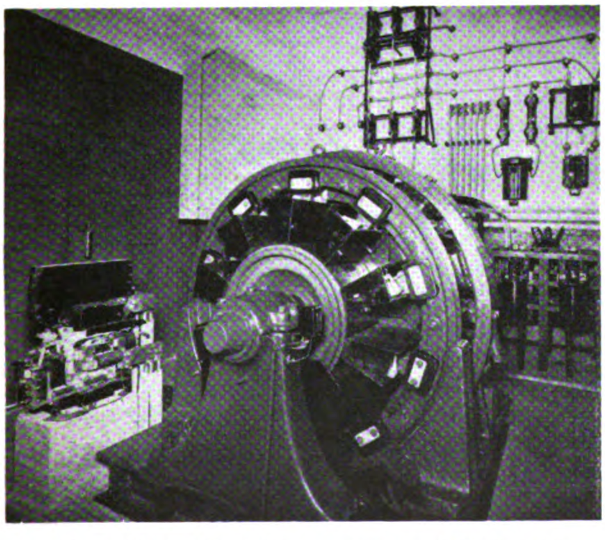


Fig. 5. The D-c. End of the Converter and the High-speed Circuit Breaker in the Pine Substation

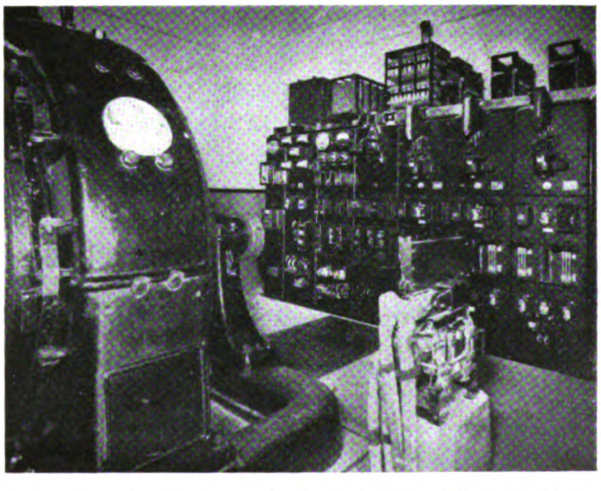


Fig. 8. Another View of the Equipment Shown in Fig. 7, with the High-speed Circuit Breaker in the Foreground

installation will be made at Pine. Colored lamp indications show whether the machines are operating, if locked out through one of the protective devices, and if the feeder circuits are open or closed. With this type of control, the towerman may prevent a machine from starting, may make the operations of such machines "continuous" or "load responsive," and can open or close the feeder circuits.

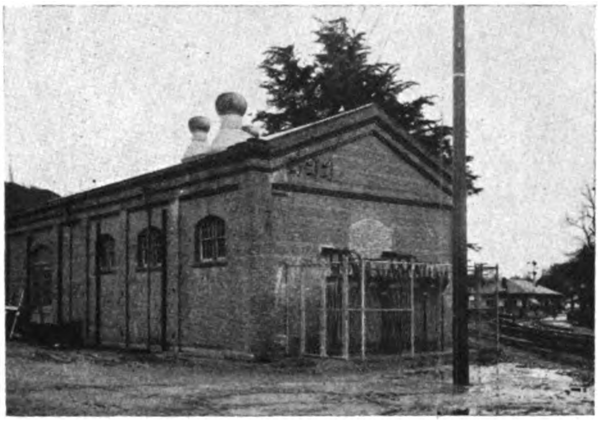


Fig. 9. The 2000-kw. Automatic Substation at San Anselmo

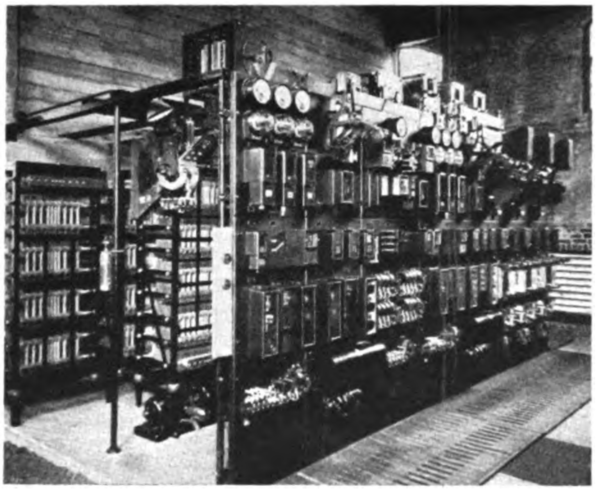


Fig. 10. The Automatic Control Equipment for the Two Synchronous Converters in the San Anselmo Substation

The engineering work of installation was carried out by the forces of the Electrical Department of the Railroad Company. The maintainer of these stations is particularly qualified by previous experience in manual substation operation and extensive automatic signalling experience which, coupled with his study and installation experience with automatic substation control, makes him proficient in this class of work. Other employees are also familiar with the maintenance of these automatic substations, with the result that the care of these plants is very satisfactory. The regular maintainer spends one day a week at the Pine and San Anselmo Substations and one day semimonthly at the Baltimore Park Substation, as the latter station operates a fewer number of hours per day than the other two. The inspection and trouble reports are carefully analyzed. Inspections cover a methodical routine, and records are made of the counter readings on the various devices for particular analysis.

Practically all the equipment outlined in the foregoing was placed in operation during 1929. The Pine Substation has been in continuous service for more than a year; the San Anselmo Substation about nine months; and the Baltimore Park Substation about seven months. Their operation has been very satisfactory.

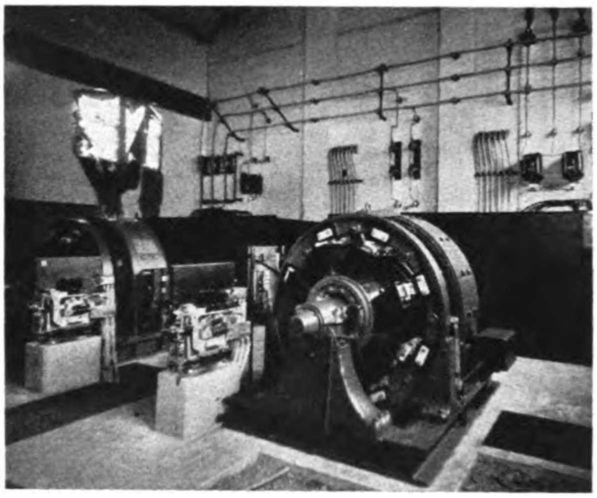


Fig. 11. The Two 1000-kw. Synchronous Converters That Are Automatically Controlled by the Equipment Shown in Fig. 10

When each substation was placed in service, improved voltage conditions were at once apparent, as evidenced by faster acceleration and increased speed of trains with consequent reduction in overall running time.

The experience of the Railroad Company clearly indicates that this installation can be added to the long list that bespeaks the success and soundness of automatic railroad substations and their operation. The complete electrical apparatus for the two new substations and the automatic switching equipment for the existing motor generator all were supplied by the General Electric Co.

Power Calculations for Elevators by the Method of Probabilities

PART I

By **BASSETT JONES**
Consulting Engineer, New York City

> *The Theory of Probabilities has given us a method of dealing with the element of chance in general. The theory and engineering analysis, together, here attack a definite problem. This mathematical treatment, tempered by engineering experience and common sense, has resulted in a basis for the selection of elevator equipment that fulfills the service requirements and yet is no larger than actually necessary.*—EDITOR

MANY engineering calculations involve statistics, and statistical methods are primarily based on the theory of probabilities. It seems unfortunate, therefore, that the curriculums of engineering schools do not thoroughly ground the student in the principles and practice of the allied subjects, probabilities and statistics. Both methods constitute a valuable mental tool kit in the study and investigation of most natural phenomena. Indeed, every event in this world of ours has more or less the character of a statistical result.

There is no field of human activity from the game of craps to the prophesying of astronomical phenomena that does not involve a degree of uncertainty and the outcome of which is not merely the most probable result of the combinations of antecedent events. Indeed, modern physical theory is fast becoming an exhibition of this fact. So, when we seek to apply probability methods to a prosaic matter such as elevator calculations, we are not departing from the manner in which nature determines what shall next happen. We are using a method of prophecy that has an apparent correspondence with nature's method, so that, given the proper antecedents, it is not at all surprising if the result of our mental dice play is to turn up the correct answer. If the answer be not a close approximation to the actual case, then we may be equally certain that some necessary antecedents have been either omitted or not properly taken into account.

From time to time the writer has presented through this channel other elevator calculations involving probabilities. Several, otherwise well informed people, have expressed surprise that the results have checked so closely with observation. But this agreement merely indicates that practically all the necessary antecedents had been considered. The method of statistics presents a very simple means of determining from data whether all the essential events have been collected and whether they have been associated in the proper order. Even the most elementary knowledge of the rules governing consistency and association of data is of invaluable assistance in such cases. The writer has seen averages in use drawn from a most formidable array of figures collected at much pains, when a simple analysis of the data either would have shown a lack of consistency, or would have given evidence of the association of the data with some unobserved factor. In a typical case, the writer used to collect miscellaneous, and more or less unguided facts as to elevator passengers. Guesses based on a vast amount of ill-assorted data of this kind led to certain rule-of-thumb methods which gave results as often wrong as right. A statistical study of the data led to discarding much as unessential, and to the collection of more essential data, which, when associated in a proper statistical manner, showed that there were but a few classes of passengers, all of those in each class behaving in a similar manner. From this an equally small number of histograms(1) were constructed. From these histograms an equal number of probability graphs gave an equivalent number of probability formulas from which the traffic chart could be drawn appropriate to any number of passengers of a particular class. By this means it has been possible to foretell the number of passengers carried in a given time with almost uncanny accuracy. A variation of ten per cent between prophecy and observation is considered too large.

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(1) A *histogram* is a step-by-step plot of observed data, arranged to show frequency of occurrence in relation to properly selected increments of change in some controlling factor; thus frequency of deaths in a given class of people with respect to increments of age, or, as another case, frequency with which any possible number of passengers out of a given initial number leave an elevator car at any floor served with respect to increments in number of passengers so leaving the car.

The smooth curve fitted to such a histogram is the *frequency graph* for that case. The statistical equation of this curve may be determined by well-known methods, and is of use in classifying and correlating the data for several cases of the same kind under a more general relation.

For the benefit of those who may care to familiarize themselves with statistical methods, the following reading is recommended, beginning with the most elementary:

Mathematical Analysis of Statistics—C. H. Forsyth.
A First Course in Statistics—D. C. Jones.
An Introduction to the Theory of Statistics—G. Udney Yule.
Probabilities and Its Engineering Uses—T. C. Fry.
The Mathematical Theory of Probabilities—Arne Fisher.

The philosophy of the theory is most ably treated in "A Treatise on Probability," by J. M. Keynes.

Probably one of the best recent examples of the proper use of statistics in the study of observed data is contained in "Studies of Human Biology," by Raymond Pearl. A beautiful example of higher statistical methods is presented by J. Willard Gibbs in "Statistical Mechanics."

The classical dynamical theory of gases and the quantum theory of radiation are, of course, illustrations of the scientific importance of statistical methods.

These data, together with the already published method of probability applied to elevator stops, give a means of determining the most probable elevator performance from the standpoint of the passengers carried.

Occupancy Factors Affecting Elevator Service

It is essential that anyone responsible for the determination of elevator plants keep himself informed as to elevator performance and building usage, both of which will vary with geographical location and even with apparently small differences in location in the same city. Only by this means is it possible to determine tendencies in use and so estimate for the future. In many of our cities the factors that affect elevator service are changing rapidly. Population densities and population class may vary widely in a short lapse of time. Five years may produce radical differences which the successful elevator engineer must be able to foretell with reasonable accuracy. He must keep himself posted on real estate conditions and on population movement. He must plan for the future as well as for the present.

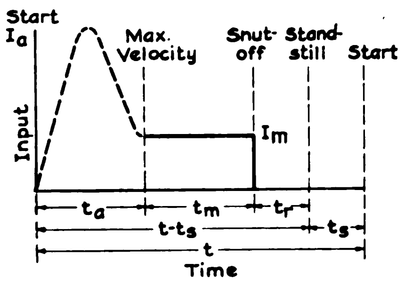

Fig. 1. Typical Duty Cycle for Elevators Going Up Under Full Load

(In this case $t-t_s=t_a+t_m+t_r$)

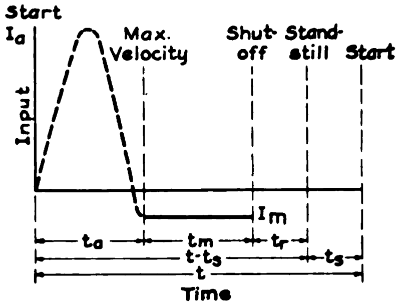

Fig. 2. Typical Duty Cycle for Elevators Going Down Under Full Load

(In this case also $t-t_s=t_a+t_m+t_r$)

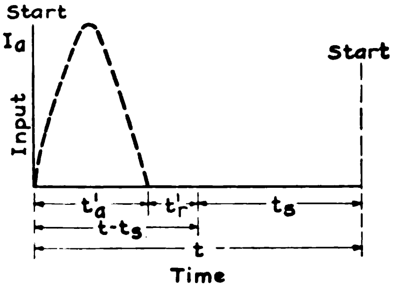

Fig. 3. A Duty Cycle for a Case in Which Maximum Velocity is Not Attained

(Here $t-t_s=t_a'+t_r'$; $t_m=0$)

For this purpose, the elevator engineer must set up in different localities "key" buildings to the records of which he can establish access. At least once a year all the essential elevator data in these buildings should be analyzed. Each year a number of all-day traffic observations sufficient to give a correct weighted mean for each period of the day should be taken. Changes in number and class of population should be recorded, and analyzed with relation to the factors producing such changes, *viz.*, alterations in business methods, changes in rents, improved horizontal transit facilities, changes in environment, enhanced renting competition, and the like.

The conditions controlling elevator service in single-purpose buildings are quite different from the similar conditions in multi-purpose buildings. Among single-purpose buildings, insurance occupancy is different from banking occupancy. Among multi-purpose buildings, professional occupancy is different from financial occupancy and still different from trade occupancy, such as that in the dry goods district. Such items of information, reduced to statistics, are the fundamental data for elevator engineering. Without these, calculations of round trip time or power consumption remain a pure hazard. Our cities are in a state of constant flux, and any hard and fast rule will too often lead to unsatisfactory results. All that follows hereafter, therefore, must be taken with this grain of salt.⁽²⁾

The Elevator Duty Cycle

At the outset it is necessary to so analyze the duty cycle of elevators that the data reached can be properly subjected to the method of probabilities in determining power input to an elevator group.

The probable number of stops and the time consumed in loading and unloading passengers, together with a proper knowledge of elevator machine performance and time consumed in opening and closing car gates and landing doors, constitutes the proper basis for the determination of round trip time. Let T_t be the calculated round trip time. This is the sum of three factors: the running time, T_r, consumed by the car in moving from stop to stop, for convenience assuming no lost time; the standing time, T_s, while the car is at rest at the landings including the time consumed in opening and closing car gates and landing doors, and waiting time when, in the ordinary course of operation, the car is standing, usually at the bottom terminal landing, for the adjustment of schedule and is neither receiving nor discharging passengers; and the lost time T_l, consumed in "inching" to level landings, false stops when the car misses a stop and has to return to the landing, or stops on false signal, and the time consumed when the car is automatically slowed down by top and bottom limits. This subdivision of the round trip time is based on the several classes of variables that enter into the problem and that may differ materially among different classes of installations and different classes of passengers. It is the writer's opinion, confirmed by years of observation, that any less detailed analysis of the round trip time is too general and may be subject to substantial error.

Let S_T be the total number of stops including the top and bottom landing. This is $S_{n-1}+2$ where

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(2) See "Elevator Service Requirements of the Modern Office Building," by Bassett Jones, GENERAL ELECTRIC REVIEW, August, 1927, p. 375.

S_{n-1} is the number of probable stops exclusive of the certain top and bottom terminal stops.(3) Then the average time between stops is $\frac{T_t}{S_T}=t$. This we shall call the *average duty cycle period.*

Referring to Figs. 1, 2, and 3, showing typical diagrammatic duty cycles, it will be seen that during each such period the car is standing still on the average a time $T_s/S_T=t_s$, and in motion a time $t-t_s$. If $t-t_s$ is greater than the sum of the acceleration time, t_a, and the retardation time, t_r, the car will reach its maximum velocity and travel at this velocity, during a time $(t-t_s)-(t_a+t_r)=t_m$, otherwise not. The hoisting engine motor will be taking power from the line certainly during the time t_a. It will be taking power from the line during the time t_m if the car be traveling up with a load greater than the sum of the friction load and the unbalanced load between car and counterweight, or when the car is traveling down with a load less than this sum. Otherwise the hoisting engine motor will be driven as a generator by the unbalanced load, and, under certain conditions, will "pump back" or deliver power to the line. If this occurs, the total energy drawn from the line during a duty cycle period is that taken during the time t_a less that returned during the time t_m. If the maximum velocity is just reached between the average spacing of stops or is not reached, then power is drawn from the line only during the accelerating time. If, as shown in Fig. 3, the maximum velocity is not reached, then the actual acceleration time, t_a' will be less than the rated acceleration time t_a. So, also, the retardation time becomes t_r'. Then

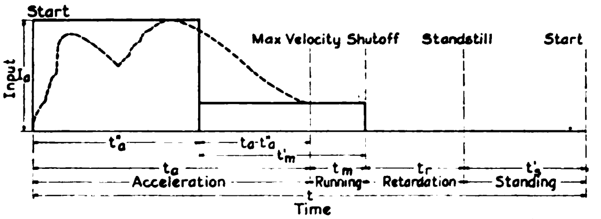

Fig. 4. The Input Characteristic for an Elevator with Resistance Control and the Corresponding Equivalent Average Duty Cycle

$$t_a'+t_r'=t-t_s$$

For any values of t_a and t_r we have, approximately,

$t_r=0.50\ t_a$ for voltage control,(4)

and $t_r=0.35\ t_a$ for resistance control.

Therefore,

$$t_a=\frac{t-t_s-t_m}{1.50}\text{ for voltage control,}$$

and

$$t_a=\frac{t-t_s-t_m}{1.35}\text{ for resistance control.}$$

The actual forms of the input curves, based on oscillograph records of direct drive, 1:1 roping, d-c. equipments, are shown by the dotted curves in Figs.4 and 5.

Of course it is possible that, owing to express runs over an extreme distance, it may be necessary to subdivide the round trip time into two parts, the time consumed during the express run and the time consumed during the local run, and to establish a duty cycle period for each.

There are two obvious methods of reducing the duty cycle to a simple approximate form amenable to reasonably simple calculations. If it were required to determine only the heating value of the duty cycle, the actual cycle could be reduced to an equivalent flat-topped cycle indicating a constant input throughout the duty-cycle period, but having the same heating value as the original cycle. But since we are interested not only in heating but also in average and peak input values, in all that follows the duty cycle will be reduced to a flat-topped form having a constant input equal to the actual maximum input but lasting for such a reduced time that the input is the same as the input of the original duty cycle. We shall divide the input during the duty cycle into two parts, first the accelerating input, second the input while running at full speed, and treat each as described in the foregoing.

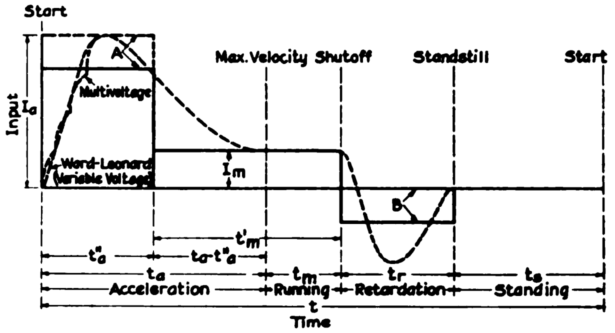

Fig. 5. The Input Curve for an Elevator with Voltage Control and Its Equivalent Average Duty Cycle

While this is obviously an approximation, it is of sufficient accuracy and results in a simple application of the probability method to the case. Were any greater accuracy in the determination of heating value desirable, it would be necessary to prepare two such equivalent flat-topped duty cycles, one based on heating value, and the other on average value, and complete two sets of calculations. But since temperature rise is a matter of safety, and should have a so-called safety factor, and since, as will be pointed out, the particular method used based on average values automatically introduces such a safety factor, in all that follows the equivalent averages will be used. This has the further advantage that the determination of time distribution of current and power input, which are properly based on average values, will be as reasonably accurate as the method permits.

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(3) "The Probable Number of Stops Made by an Elevator," by Bassett Jones, GENERAL ELECTRIC REVIEW, Aug., 1923, p. 583. Also "Note on the Probable Number of Stops Made by an Elevator," by Bassett Jones, GENERAL ELECTRIC REVIEW, June, 1926, p. 425.

(4) The factor 0.50 for voltage control will, and has approached 1.0 with improvements in the art. However, this change does not materially alter the final conclusions reached in this article.

Therefore, for our purpose it will be sufficiently accurate if the input during acceleration, or the area under the curve during acceleration, be taken as a constant input equal to the maximum input during a reduced time t_a'' such that the area established by the constant input curve equals the area corresponding to the actual input curve. The time $t_a - t_a''$ is to be added to the time t_m during which the car is traveling at maximum velocity, making it $t_m' = t_m + (t_a - t_a'')$ as shown in Fig. 6, which gives the rectangular input curve equivalent to the input curve of Fig. 1. Similar constructions for the cases of Figs. 4 and 5 are shown on those figures. The areas of the two rectangles equal the total area under the entire input curve during the time $t_a + t_m$.

In determining energy input over a given time, the regenerative pump back during retardation with voltage control is equivalently deducted from the accelerating input. This reduces the acceleration input about 15 per cent. Therefore it is assumed that during the retardation time, t_r, the motor is neither taking current from the line nor generating; and in such cases the time t_r is to be added to t_s, making it t_s'.

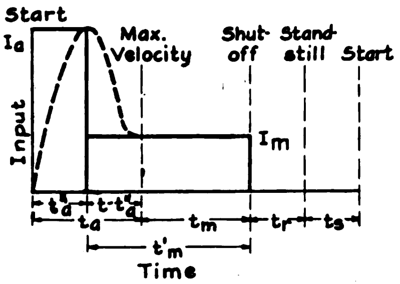


Fig. 6. The Equivalent Duty Cycle for the Case Shown in Fig. 1

If the problem is not input, but temperature rating of feeders, protective devices, etc., then the pump-back current may either pass into the feeder or directly to other motors in the group. Hence, it will be effective either in increasing or in decreasing the temperature of the feeder. Therefore the accelerating input should be correspondingly increased or decreased by an amount, i, given by

$$i = (I_a^2 + I_r^2)^{\frac{1}{2}} - I_a$$

where I_r is the average value of the pump-back current. The value of i is nearly correct in the case of voltage control when t_a'' can be taken equal to t_r. But since I_r is nearly $0.15 I_a$, this amounts to increasing I_a by an amount slightly more than $0.01 I_a$, and can be neglected. Therefore, in computing r.m.s. values, the pump back due to regenerative braking is omitted and t_r added to t_s, giving t_s'. The accelerating input, I_a, is taken at its full value.

Generally, with resistance control, if $t_a = 5.0$ sec., then $t_a'' = 3.0$ sec.; and $t_a - t_a'' = 2.0$ sec. are to be added to t_m. With voltage control, if $t_a = 3.0$ sec., then $t_a'' = 1.5$ sec.; and 1.5 sec. are to be added to t_m. In either case, if the input curve of Fig. 3 applies, the values of t_a'' are to be reduced proportionally. Thus, with voltage control, if full speed is not reached and $t_a' = 2.0$ sec. when $t_a = 3.0$ sec., $t_a'' = 1.0$ sec. Since, in this case, $t_m = 0$, the extra second added to t_m gives $t_m = 1.0$. These results are obtained from graphical studies of oscillograph records of 1:1 roping traction machines.

We are now able to build up an equivalent rectangular duty cycle for the entire period. Such a cycle is shown in Fig. 7 for a particular case, of which more is said later.

Current Input

The next step is to give proper numerical values to the input. Since our object is to establish the proper rating of feeders, and protective devices, this will be given in terms of current.

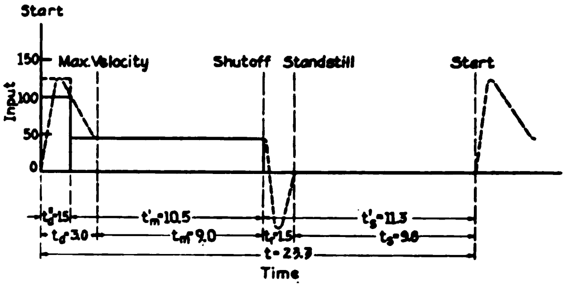


Fig. 7. The Average Duty Cycle for a Particular Case of Voltage Control and Balanced Load

Table I gives amperes input for a case where the rated load is 2500 lb. and the rated velocity 600 ft. per min., the hoisting engines being direct-drive 1:1 roping equipped with 240-volt d-c. motors.

TABLE I

VALUES OF INPUT

(These values are adjusted averages and will vary from case to case and with improvements in the art.)

Load lb.	Motion	Accel. Max. Amp. I_a	Running Amp. I_m
(*A*) Resistance Control: ($t_a = 5.0$ sec.)			
2500	Up	210	140
2500	Down	185	−50
1000	Up or down	200	45
150	Up	190	−15
150	Down	205	85
(*B*) Voltage Control: ($t_a = 3.0$ sec.)			
2500	Up	250	140
2500	Down	182	−50
1000	Up or down	190	45
150	Up	178	−10
150	Down	205	90

Assuming the load and moving masses fixed, the change in input at some other maximum velocity or acceleration time (or both) for which measured data are not available, may be approximated as follows:

If the acceleration time is fixed at 3.0 sec. but the maximum velocity, V_m, varies, the input during acceleration varies as the square of the velocity V_m, and the running input varies directly as the velocity V_m.

If the maximum velocity remains fixed at 600 ft. per min. (10 ft. per sec.), but the acceleration time varies, the input during acceleration, I_a, varies inversely as the accelerating time. The running input, I_m, of course, remains as before.

If both maximum velocity and acceleration time vary, the input during acceleration, I_a, varies as V_m^2/t_a and the running input, I_m, varies as V_m.

As an example, assume $V_m = 13.33$ ft. per sec. (800 ft. per min.) and $t_a = 4.0$ sec., voltage control,

Then

$$\frac{I_a'}{I_a} = \frac{13.33^2}{4.0} \div \frac{10^2}{3} = \frac{177.7\times 3}{100\times 4} = \frac{533}{400} = 1.33$$

or

$$I_a' = 1.33\times I_a = 1.33\times 250 = 333 \text{ amp.}$$

is the new maximum accelerating peak.

$$\text{Also } \frac{I_m'}{I_m} = \frac{13.33}{10} = 1.33$$

$$\text{or } I_m' = 1.33\times 140 = 224 \text{ amp.}$$

is the new running current.

Note that for the given maximum load (2500 lb.) and the corresponding masses including moving parts of hoisting engine, ropes, car and counterweights, both the accelerating and running inputs for voltage control vary as above by the same factor if the following rated velocities and acceleration times (Table II) are used:

TABLE II

INPUT FACTORS (VOLTAGE CONTROL)

Velocity, ft. per min.	Accel. Time sec.	Factor
600	3.0	1.0
700	3.5	1.16
800	4.0	1.33
900	4.5	1.50
1000	5.0	1.67

Of course if the maximum load is different from that given (2500 lb.) the masses will vary also. Then the input during acceleration will vary in proportion to $\frac{WV^2}{gt_a}$, where W is the total weight of all moving parts given in pounds. Similarly the running input will vary as $\frac{WV_m}{g}$.

A Definite Case

The equivalent duty cycle given in Fig. 7 is for the case of voltage control given above, in (*B*) Table I when $T_t = 140$ sec., $T_s = 59$ sec., $S_T = 6$. Then $t = 140/6 = 23.3$ sec., $t_s = 59/6 = 9.8$ sec., and $t - t_s = 13.5$ sec.

In this case $t_a + t_r = 4.5$ sec. (assuming balanced load condition as an average). Then $t_m = (t - t_s) - (t_a + t_r) = 9.0$ sec. is the time the car is traveling at maximum velocity. Since, for this case $t_a = 3.0$ sec. and $t_a'' = 1.5$ sec., the remaining 1.5 sec. is to be added to the running time making it $t_m' = 9.0 + 1.5 = 10.5$ sec.

Since balanced load conditions are assumed, the input during the time $t_a'' = 1.5$ sec. is 190 amp., less 15 per cent to allow for regenerative braking during retardation, or 162 amp.; and the input during the running time $t_m' = 10.5$ sec. is 45 amp.

If the traffic is such that the car is operating with an average load equal to balanced load on the up motion, and with light load (150 lb.) on the down motion, then it will be sufficiently accurate if the accelerating input be taken as the average input, $\frac{190+205}{2} = 198$ amp., under these two conditions; and, similarly, for the running input, $\frac{45+90}{2} = 68$ amp. Just what values of input should be used in any case will depend on the traffic conditions.

It is important to recognize the fact that when the type of voltage control known as multi-voltage is used, in which rotating apparatus is used to establish definite voltage steps, the losses are materially less than with the individual motor-generator type of voltage control. The current values given to the duty cycle will be different in the two cases.

Average and R.M.S. Input for a Single Motor

Next to be noted is that the accelerating input occurs during $t_a''/t = p_a = 1.5/23.3 = 0.064$ of the duty cycle period; also, that the running input occurs during $t_m'/t = p_m = 10.5/23.3 = 0.45$ of the duty cycle period.

The *average input* over the whole period is therefore $p_a\ I_a = 0.064\times 198 = 12.7$ amp. for the acceleration input and $p_m\ I_m = 0.45\times 68 = 30.6$ amp. for the running input, a total *average continuous input*, I_A, of 43.3 amp.

The equivalent continuous r.m.s., or heating, value of the input current during the duty cycle, from which the carrying capacity of the conductors selected must be determined, remembering that in this case the accelerating input is taken at its full value unchanged to allow for pump back, is found as follows:

For the accelerating input, the equivalent continuous r.m.s. input, I_{Ra}, is given by

$$I_a^2 p_a t = I_{Ra}^2 t,$$

whence,

$$I_{Ra} = I_a p_a^{\frac{1}{2}}.$$

For the running input, the equivalent continuous r.m.s. input, I_{Rm}, is given by

$$I_m^2 p_m t = I_{Rm}^2 t,$$

whence,

$$I_{Rm} = I_m p_m^{\frac{1}{2}}.$$

The total continuous r.m.s. input, I_R, is

$$I_R = I_{Ra} + I_{Rm} = I_a p_a^{\frac{1}{2}} + I_m p_m^{\frac{1}{2}}.$$

In the case given this is $190 \times (0.064)^{\frac{1}{2}} + 45 \times (0.45)^{\frac{1}{2}} = 47.5 + 30.2 = 77.7$ amp., or approximately 1.8 times the average current. Approximate values of $p^{\frac{1}{2}}$ are given in Table III.

If maximum conditions were used in determining r.m.s. values, $I_a = 250$, $I_m = 140$. Assume the same values of p_a and p_m. In other words, assume that t, t_s, t_r, t_a remain the same. Then

$$I_R = 250 \times (0.064)^{\frac{1}{2}} + 140 \times (0.45)^{\frac{1}{2}}$$
$$= 157 \text{ amp. r.m.s.}$$

Fuses or other temperature protective devices selected on this basis would give no protection to a motor properly proportioned for its actual duty of about 78 amp. continuous r.m.s. input. Indeed, if such devices were selected on the basis of the actual maximum running current of 140 amp. they would utterly fail to protect such a motor; and this is a real defect in the present method of selecting such fuses. On the basis of 240 volts, 85 per cent efficiency, and 78 amp. continuous input, the required continuous output in the above case is practically 30 h.p. If allowance is made for more severe duty such as might reasonably occur, a 40-h.p. motor may be selected. Then, fuses selected on the basis of the maximum running current of 140 amp. alone would permit a continuous overload on a motor that would ordinarily be picked for 50-deg. rise and for, at most, two hours continuous full-load duty.

TABLE III

OPERATING FACTOR VALUES

p	0.02	0.03	0.04	0.05	0.06	0.07	0.08
$p^{\frac{1}{2}}$	0.04	0.18	0.20	0.22	0.25	0.27	0.28
p	0.09	0.10	0.15	0.20	0.25	0.30	0.35
$p^{\frac{1}{2}}$	0.30	0.32	0.39	0.45	0.50	0.55	0.59
p	0.40	0.45	0.50	0.55	0.60	0.65	0.70
$p^{\frac{1}{2}}$	0.63	0.67	0.71	0.74	0.78	0.81	0.84

Obviously it would merely waste money to install leads to this motor based on anything more than its rated full-load input, if as much.

In the foregoing there is an error in assuming that the maximum current during acceleration can be directly compared with the actual time distribution of the accelerating current as to heating value. However the error is on the safe side, but, as will appear in the following, not any safer than is desirable.

Average and R.M.S. Input to a Group of Motors

If now a number, N, of such motors, all operating on the same average duty cycle, are drawing current from a single feeder, the average and r.m.s. input to the group may be determined as follows:

The probability, P_r that any number, r, of such motors are operating simultaneously at any time is given by a basic probability formula,

$$P_r = N_{C_r} p^r (1-p)^{N-r} \qquad (1)$$

where p is the *operating factor* as previously described (either for acceleration, p_a, or for running, p_m) and where N_{C_r} is the number of combinations of N things taken r at a time. In one case we find the probability that r motors are accelerating simultaneously. In the other case we find the probability that r motors are running simultaneously.

The average input due to the entire group is given by

$$I_A = I\,(P_1 + 2P_2 + 3P_3 + \cdots NP_N) \qquad (2)$$

where I is an accelerating input or the running input of a single motor, found as above. Using I_a and the proper values of P_1, P_2, $P_3 \cdots P_N$ as found by Equation (1), the average accelerating input is obtained. Using I_m and the proper values of P_1, P_2, $P_3 \cdots P_N$, the average running input is obtained. The sum of these is the *total average input*.

The expression (2) can be easily calculated by knowing that $(P_1 + 2P_2 + 3P_3 + \cdots + NP_N) = pN$, where p is the proper value of the operating factor. Therefore,

$$I_A = IpN \qquad (3)$$

The value of I_A is to be used in determining the power required by the group or the kilowatt-hours consumed during the time in which the established duty cycle may be assumed as constant.

Now as to the r.m.s. value of the input. It is given by

$$I_R = (P_1 + 4P_2 + 9P_3 + \cdots + N^2P_N)^{\frac{1}{2}}\, I \qquad (4)$$

where again, I with the proper values of $P_1, P_2, P_3 \cdots P_N$ found by (1) gives the r.m.s. accelerating input, and I_m with the proper values of P_1, P_2, $P_3 \cdots P_N$ gives the r.m.s. running input. The sum of these is the *total r.m.s. input*, from which the current-carrying capacity of the feeder may be determined, selecting a size of conductor the continuous rating of which equals the total r.m.s. input.

In order to abbreviate the work, the values of $(P_1 + 2P_2 + 3P_3 + \cdots + NP_N)$ and $(P_1 + 4P_2 + 9P_3 + \cdots + N^2P_N)^{\frac{1}{2}}$ may be calculated for a useful range of values of N and p. These are given in Fig. 8 in terms of p and of $F = \dfrac{\text{r.m.s.}}{\text{average}}$ or

$$F = \frac{(P_1 + 4P_2 + 9P_3 + \cdots + N^2P_N)^{\frac{1}{2}}}{(P_1 + 2P_2 + 3P_3 + \cdots + NP_N)} \qquad (5)$$

and for $N = 6$, 8, 10, 12, 15, and 20.

It will be noted that the r.m.s. value exceeds the average value both as p decreases and as N decreases. When $p=0.50$ the entire range falls between r.m.s. value = 1.03 × average and r.m.s. value = 1.06 × average.

As an example, let $N=10$, $p=0.10$ and $I=200$. Then by Equation (3) $I_A=200\times0.10\times10=200$, and from Fig. 8, $F=1.38$. Therefore $I_R=1.38\times200=276$.

Peaks

For the purpose of determining the setting of protective devices in the circuit of such a group of motors, and to set commutating conditions, or for determining the load-factor or the probable demand affecting generating apparatus or power service rates, it is necessary to estimate the probable peaks and their frequency. For this purpose the several values of P_0, P_1, $P_2 \cdots P_N$ for values of p and N usual in elevator practice, *viz.*, for banks of six and eight elevators, are given in Table IV.

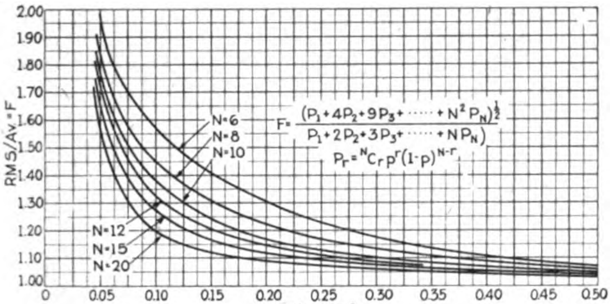


Fig. 8. The Ratio of Root-mean-square to Average Values of Input for Various Operating Factors (p) and Numbers of Motors (N)

The probability that any two such events will occur simultaneously is the product of their individual probabilities. Thus, under $N=8$ for $p=0.10$, find $P_4=0.0046$, and under $N=8$, for $p=0.25$, find $P_2=0.312$. Then the probability that these two events, assumed associated, will occur together is $P=0.0046\times0.312=0.00143$.

Let us, for example, assume that in such a bank of eight elevators, $p_a=0.10$, and $p_m=0.25$. Then the probability that four cars will start simultaneously at any time is $P_4=0.0046$, and the probability that two cars will be running simultaneously is $P_2=0.312$. Then the probability that four cars will start simultaneously while, at the same time, two cars are running is $P=0.00143$. Assume that for this bank $t=25$ seconds. Therefore on the average every elevator will start and run every 25 seconds; or there will be a total $60/25\times60=144$ starts and runs every hour, of which $0.00143\times144=0.2$ will result in the combination being considered. Therefore the combination will occur on the average once in five hours, which, since it is hardly possible that the bank will continue to operate in this way for five hours, means that this event is improbable in any one day. There are of course other events, some of them possibly involving even greater peaks, that will occur with greater frequency. This part of the problem can be solved only by trial without recourse to a more complicated method.

A calculated point-to-point frequency graph for the case of six motors where $p_m=0.50$ and $p_a=0.25$ is given in Fig. 9. (If Fig. 9 had been plotted from *observed* data, it would be a ***histogram*** for this case.) By the use of such frequencies it is possible to lay out a point-to-point time graph of the probable input to such a group of motors, which represents the equivalent of a graphical instrument record of the probable load fluctuations. Thus, as in the above case for eight elevators $p_a=0.10$, $p_m=0.25$, the load equivalent to two cars running for which $P_2=0.312$ will occur $0.312\times144=44.9$ times per hour, or every 1.34 seconds, giving a point of the time graph with this frequency for this input. When a sufficient number of such points for various combinations of starting and running have been plotted, the point-to-point curve may be drawn. This method does not give any direct knowledge of the duration of such peaks. A probability method that will give probable duration can be used, but experience shows that here again the added complication is not necessary for practical purposes. The most probable average duration of a peak is 0.5 times the duration of the component peaks, that is, $\frac{pt}{2}$.

Such a graph covering a period of 15 minutes is given in Figs. 10, 11, and 12 for 16 passenger elevators in two banks of eight each and a third bank of four

TABLE IV

PROBABILITY DATA FOR GIVEN VALUES OF p AND N

	$p=0.05$		$p=0.10$		$p=0.15$		$p=0.25$		$p=0.35$		$p=0.45$	
	$N=8$	$N=6$	$N=8$	$N=6$	$N=8$	$N=6$	$N=8$	$N=6$	$N=8$	$N=6$	$N=8$	$N=6$
P_0	0.664	0.746	0.431	0.531	0.273	0.377	0.100	0.178	0.0318	0.0754	0.0084	0.0277
P_1	0.272	0.232	0.382	0.355	0.384	0.400	0.264	0.370	0.137	0.244	0.0556	0.1363
P_2	0.052	0.0306	0.149	0.0984	0.238	0.196	0.312	0.292	0.258	0.327	0.159	0.282
P_3	0.0054	0.00020	0.033	0.0146	0.085	0.0415	0.214	0.132	0.399	0.236	0.259	0.3025
P_4	0.00036	0.000085	0.0046	0.0012	0.018	0.0058	0.0867	0.0269	0.188	0.0950	0.263	0.1863
P_5	0.000014	0.0000018	0.00041	0.000001	0.0026	0.00039	0.0230	0.0044	0.082	0.0205	0.172	0.0574
P_6	0.0000004	......	0.000023	......	0.00023	0.000011	0.038	0.00024	0.022	0.0018	0.070	0.0083
P_7	......	......	0.0000007	......	0.00001	......	0.00037	......	0.003	......	0.0163	......
P_8	......	......	......	......	0.0000003	......	0.00002	......	0.0002	......	0.0017	......

cars which are used as both passenger and service elevators. The running graph is given in Fig. 10, the starting graph in Fig. 11, and the combined running and starting in Fig. 12. It is interesting to note that the greatest fluctuations are due to running, not starting, the reason for which will appear later. The r.m.s. value of Fig. 12 and the frequency and amount of the largest peaks were used to select the type, form, and capacity of the generators supplying the power, and to determine their operating characteristics. The actual observed loads, and fluctuations in time are extraordinarily close to the calculated values, not, of course in detail form but in average frequency and amount of the power fluctuations.

Example

Let us now work out an actual case complete. Here $N=8$, $T_t=180$ sec., $T_s=91.3$ sec., $S_T=11$. The duty cycle period, t, is $180/11=16.3$ sec. of which, $91.3/11=8.3$ sec. is t_s. Then $t-t_s=8.0$ sec.

The elevators are rated 2500 lb., 800 ft. per min., 4.0 sec. acceleration, voltage control (generator-voltage control type). Therefore $t_a=4.0$ sec., $t_r=2.0$ sec., and since $t_a+t_r=6.0$ sec., $t_m=(t-t_s)-(t_a+t_r)=2.0$ sec. This case will be treated for two conditions: First, when the car has balanced load in both directions of motion; second, when the car leaves the bottom terminal with full load, drops the load on the way, and arrives at the top terminal with light load (150 lb.). It will therefore be assumed that the average load during up motion is balanced load. In this case, on the down motion the car carries light load. The second case is typical of arrival traffic.

The equivalent input during acceleration is $I_a=1.33\times 190=253$ amp. less 15 per cent or 215 amp. for 2.0 sec. (see Tables I and II). Therefore $t_a'=4$ sec. $-$ 2 sec. $=2.0$ sec.; also, $t_m'=4.0$ sec., for which $I_m=45\times 1.33=60$ amp.

Then, $p_a=2.0/16.3=0.1225$, and $p_m=4.0/16.3=0.2450$.

The average accelerating input is $215\times 0.1225\times 8=210.7$ amp. The average running input is $60\times 0.2450\times 8=117$ amp. The total average is 328 amp. A new average value of accelerating input, making no correction for pump back, is required. It is $253\times 0.1225\times 8=248$ amp. Then for $N=8$ and $p_a=0.1225$, the value of F from Fig. 8 is 1.41, and the r.m.s. accelerating input is $248\times 1.41=349.7$ amp. Since, for $p_m=0.245$, $F=1.19$, the r.m.s. running input is $117\times 1.19=139.5$ amp. The total r.m.s. value is 489.2 amp.

The hoist is 417 feet. Therefore each car travels 834 ft. in 180 sec. or in three minutes. In one hour each car travels $20\times 834=16{,}680$ ft., or 3.15 miles per hour, and makes a total of 70 stops per car mile. The eight cars thus travel 25.20 miles in one hour.

Since the average input is 328 amp., the kilowatt input at 240 volts is 78.7 or 78.7 kilowatt-hours per hour. The kilowatt-hours per car mile is found to be 3.12, which is not far out of the way for balanced load, voltage control and 70 stops per car mile.

The worst conditions may exist during the arrival period, when the car is traveling up averaging balanced load and down with light load.

The duty cycle elements are then $T_t=162$ sec., $T_s=77$ sec., $S_T=8.5$. The duty-cycle period t is $162/8.5=19.1$ sec., of which $77/8.5=9.1=t_s$, and $t-t_s=10$ sec.

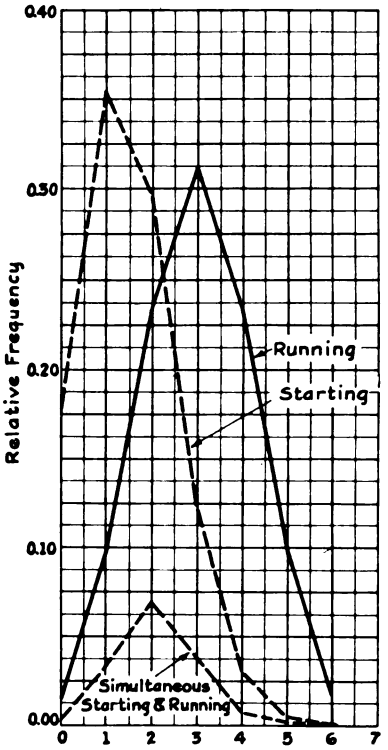


Fig. 9. A Point-to-point Frequency Graph for Six Motors

For the average of up balanced load and down light load, from the time-speed characteristics of this equipment, is found, $t_a+t_r=6.8$ sec. Therefore $t_m=3.2$ sec., and, as before, $t_a'=2.0$ sec. Therefore $t_m'=5.2$ sec.

Then $p_a=2.0/19.1=0.1045$ and $p\ =5.2/19.1=0.272$.

The average rated input for the average duty cycle is to be taken as the mean of input during up motion balanced load, and the input during down motion light load. For acceleration (see Tables I and II) it is

Up motion: $190\times 1.33=253$ amp. less 15 per cent for pump back, or 215 amp.

Down motion: $205\times 1.33=270$ amp. less 15 per cent or 230 amp.

The mean is $I_a=222.5$ amp.

For running it is

Up motion: $45\times 1.33=60$ amp.

Down motion: $90\times 1.33=119.7$ amp.

The mean is $I_m=89.9$ amp.

The average accelerating input is $222.5 \times 0.105 \times 8 = 186.9$ amp.

The average running input is $89.9 \times 0.27 \times 8 = 195$ amp.

The total average is 382 amp.

Since, for $p_m = 0.272$, $F = 1.16$, the r.m.s. running input is $195 \times 1.16 = 226$ amp.

The total r.m.s. value is 542 amp. Therefore the feeder to this bank should be based on approximately 542 amp. continuous duty.

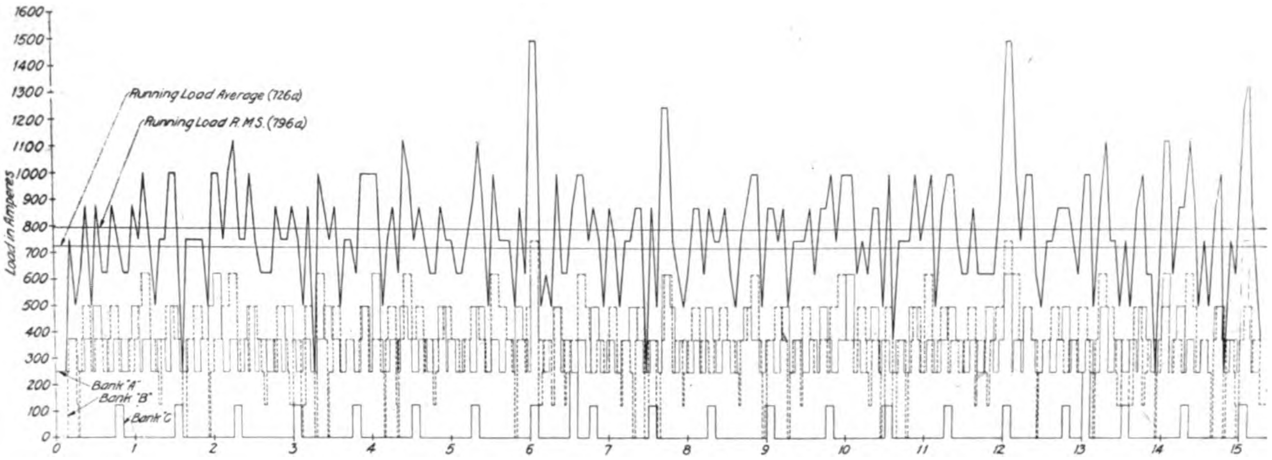


Fig. 10. A Running Graph of a Typical Group of Elevators Plotted by the Point-to-point Method for a Period of Fifteen Minutes

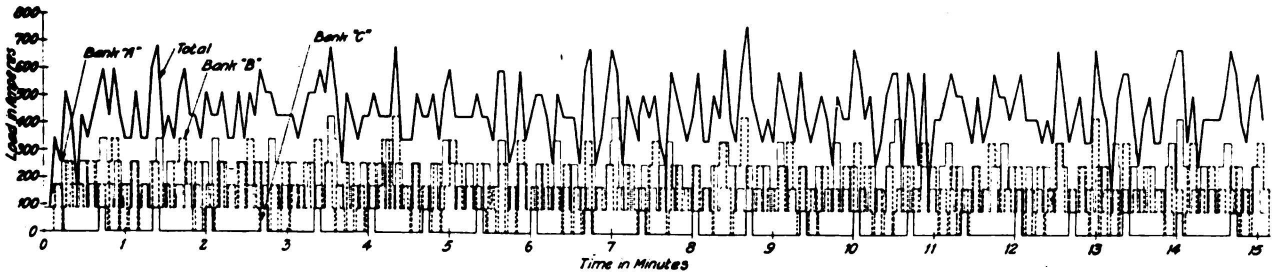


Fig. 11. The Starting Graph for the Elevators of Fig. 10

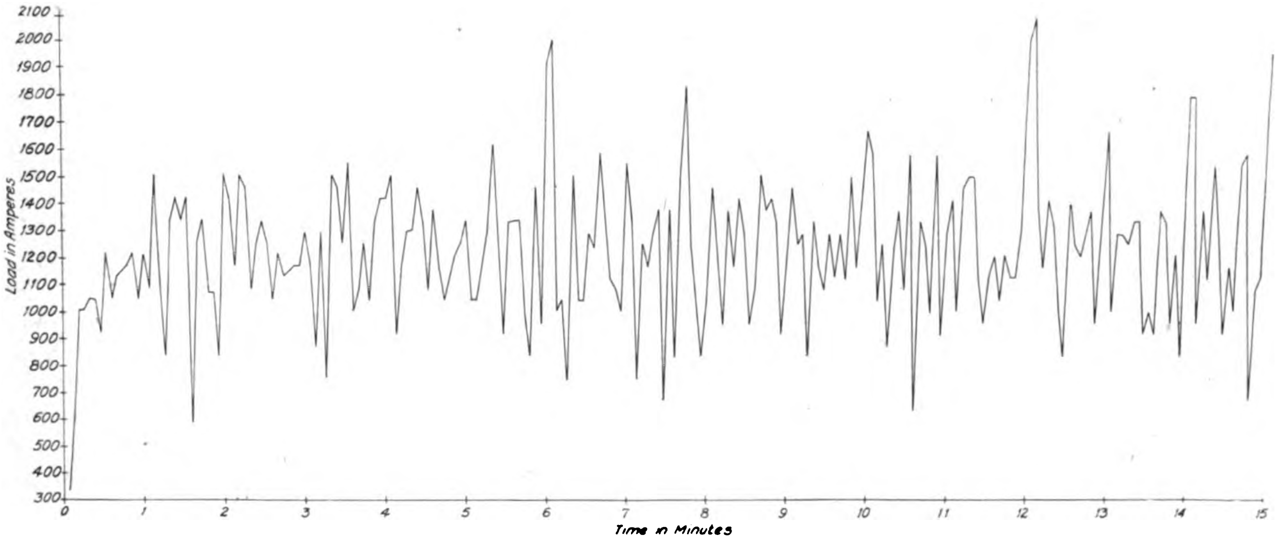


Fig. 12. The Combined Running and Starting Frequency Graph for the Elevators of Figs. 10 and 11

The mean accelerating input not corrected for pump back is $1/2\ (253+270) = 261$ amp. The corresponding average accelerating input is $261 \times 0.105 \times 8 = 219.2$ amp.

Since $N = 8$, and $p_a = 0.105$, from Fig. 8, $F = 1.44$. Therefore the r.m.s. accelerating input is $219.2 \times 1.44 = 315.6$ amp.

The average kw. input is $\frac{382 \times 240}{1000} = 91.5$.

The eight cars travel a total of 28 car miles in an hour and consume 3.25 kw-hr. per car mile, with 57 stops per car mile.

If all the foregoing conditions hold except that the car travels with full load over the entire run, then the total average input becomes 552 amp., the total r.m.s. input becomes 585 amp. and the kw-hr. per car mile reach the value 4.73, all of which shows how necessary it is to determine the probable demands on the elevator before the apparatus can be intelligently selected, or proportioned for its duty.

Next let us form some idea of the fluctuations in the input demand for this bank. Assume conditions as in the case of arrival traffic previously considered; up, balanced load; down, light load.

Then, for $p_a = 0.105$ is taken the value 0.10 and for $p_m = 0.272$ is taken 0.25 for reference to Table IV where, under $N = 8$ are found factors corresponding to these values of p.

The average accelerating input not corrected for pump back is 219 amp. and corresponds to $\frac{219}{261} = 0.84$ car accelerating (note that $p_a\ N = 0.105 \times 8 = 0.84$). Therefore any number of cars more than one accelerating simultaneously will constitute a peak above the average. Also the average running input is 195 amp. and corresponds to $195/89.9 = 2.17$ cars running simultaneously. Therefore any number of cars over two running simultaneously will constitute a peak above the average.

Let us try two cars accelerating, $P_2 = 0.149$, and three cars running, $P_3 = 0.214$. The combined frequency is $P = 0.149 \times 0.214 = 0.0319$. Each car starts and runs on the average $\frac{2700}{19.1} = 141.5$ times in 45 min. Of these, $0.032 \times 141.5 = 4.5$ will coincide with the condition under consideration. On the average the input will reach $(2 \times 222.5) + (3 \times 89.9) = 715$ amp. every $45/4.5 = 10$ min.

Next take three cars accelerating and three running. Then $P = 0.033 \times 0.214 = 0.0071$. The frequency is $0.0071 \times 141.5 = 1.00$ or a starting and running once every 45 min. The corresponding input is 937 amp.

Next, take three cars accelerating and four running. Then $P = 0.033 \times 0.0876 = 0.0029$. The frequency is $0.0029 \times 141.5 = 0.41$, or once every 109 min. The corresponding input is 1027 amp., and since this operating period is 45 min. a day this peak may occur once every other day or so.

Such infrequent peaks do not necessarily affect the feeder carrying capacity; but they do affect the protective devices. In this way the calculations point out the distinct advantage of overload and time-limit circuit breaker protection of elevator feeders.

It is obvious from the preceding considerations that occasional peaks of considerable magnitude relative to the average may occur. Fortunately, the heavier the peak, as a general thing, the shorter is its duration. When fuses are used for the protection of elevator feeders, the fuse may acquire a fairly high temperature and blow when one of these excessive peaks comes along. Such cases have happened, and in one case, where fuses were used on the local utility company's service panel, while a time-limit overload circuit breaker was used on the house board, the circuit breaker stayed in but the service feeder fuses blew, in spite of the fact that the utility company had been informed of the probability.

Another point of interest in connection with such peaks is that when the building is emptying at night, the elevators are running up light and down heavily loaded, generating during the running time in both directions. When a large number of elevators are in use, this pump back, small for each machine, may occasionally combine into a generated peak of some magnitude. Cases have occurred where the elevators so acting as generators have momentarily fed the entire remaining load in the building. In one case, where the building is served by an isolated plant, reverse-current relays on the generator breakers are all that have prevented the elevators from occasionally motorizing the generators. The law of probabilities enabled this to be foreseen and the proper precautions taken in advance.

R.M.S. Rating of Conductors

The r.m.s. rating of conductors seems to be a rational basis for a method of selecting feeder sizes. The drop or potential loss in such feeders will be determined by the duration of the maximum voltage fluctuation that will not trip the elevator control devices. Fluctuations greater than this will be of too short a duration to release the control contacts. Ordinarily, the drop may be determined on the basis of the r.m.s. current, as this gives some leeway over the average. This practice may call for a feeder of carrying capacity greater than the r.m.s. current, but the calculations lead to a distinct economy over common present practice as will be pointed out.

A selection of feeders based on a purely empirical, or rule-of-thumb method that has no relation to duty cycle, generally leads to wasteful installations. In practically every case, the carrying capacity of feeders determined by the r.m.s. method has been about 50 per cent of the carrying capacity of feeders determined by such rules. Nevertheless, wherever such feeders selected on the basis recommended in this article have been used, they have proved to be ample for the duty. Obviously fuses selected on the usual empirical basis generally will not provide adequate protection against prolonged overloads.

The method of selecting lines to individual motors may be simplified by noting that, since the total r.m.s. current for both accelerating and running is $I_R = I_a p_a^{\frac{1}{2}} + I_m p_m^{\frac{1}{2}}$, I_a may be given in terms of I_m, thus $I_a = x\,I_m$, so,

$$I_r = I_m \left(p_a^{\frac{1}{2}} + x\,p_m^{\frac{1}{2}}\right) \qquad (6)$$

The expression $(p_a^{\frac{1}{2}} + x\,p_m^{\frac{1}{2}})$ may be called the "duty-cycle factor." It can be tabulated or charted by giving a range of values to p_a, p_m and x, and, for elevators certainly, the determination of proper motor leads and fuses can be made a standard operation—a rule that has some real bearing on the case.

Form of Calculation for an Actual Case

The following additional case, free from discussion, is given to show that the calculations required are not unduly complicated.

The data for arrival traffic are:

Eight elevators rated at 3000 lb., 800 f.p.m., voltage control, 250 volts, direct current. Total hoist $H_T = 173$ ft.; Total stops $S_T = 11$; Round trip time $T_t = 164$ sec.; Standing time $T_s = 61$ sec.; Running time $T_r = 103$ sec.

In this case there is no purely express run so the stops are treated as though they are equally distributed over the round trip.

The duty-cycle elements are:

(1). Average time, start to start, $t = T_t/S_T = 164/11 = 14.9$ (15) sec.

(2). Average standing time, $t_s = T_s/S_T = 61/11 = 5.5$ sec.

(3). Standing time corrected for retardation time t_r is $t_s' = t_s + t_r = 5.5 + 2 = 7.5$ sec.

(4). Actual acceleration time, $t_a = 4.0$ sec.

(5). Reduced acceleration time, $t_a'' = 2.0$ sec. The reduction is 2.0 sec. because this is a case of voltage control.

(6). Actual time at maximum speed, $t_m = t - (t_a + t_r) - t_s' = 15 - 6 - 7.5 = 1.5$ sec.

(7). Corrected time at maximum speed, $t_m'' = t_m + (t_a - t_a'') = 1.5 + 2 = 3.5$ sec.

(8). Operating factor during acceleration, $p_a = t_a''/t = 2/15 = 0.133$.

(9). Operating factor during maximum speed, $p_m = t_m''/t = 3.5/15 = 0.233$.

(10). For this case,

I_a for up motion balanced load = 304 amp.
I_a for down motion light load = 324 amp.
Ave. $I_a = 314$ amp.
I_m for up motion balanced load = 72 amp.
I_m for down motion light load = 144 amp.
Ave. $I_m = 108$ amp.

Then, by Equation (3), and reducing the average I_a by 15 per cent to allow for pump back during retardation:

Ave. accelerating input $= 0.85\ N p_a I_a = 8 \times 0.133 \times 267 = 285$ amp.

Ave. maximum speed input $= N p_m I_m = 8 \times 0.233 \times 108 = 201$ amp.

Total ave. input $= 285 + 201 = 486$ amp.

(11). Now since, as has been shown, the full value of I_a is to be used in finding the r.m.s. value, $N p_a I_a = 8 \times 0.133 \times 314 = 334$. Then, from Fig. 8, find for $N = 8$ and $p_a = 0.133$, $F = 1.35$, and for $N = 8$ and $p_m = 0.233$, $F = 1.18$.

Then,

r.m.s. accelerating input $= 334 \times 1.35 = 450$ amp.
r.m.s. maximum speed input $= 201 \times 1.18 = 239$ amp.

Total r.m.s. input $= 450 + 239 = 689$ amp.

(12). Next find the probable peaks:

Total ave. input/ave. accelerating input $= 486/267 = 1.82$, so that even two cars accelerating simultaneously produce a peak in excess of the average.

Total ave. input/ave. maximum speed input $= 486/108 = 4.5$, so that more than five cars running simultaneously at maximum speed produce a peak in excess of the average.

(13). Assume four cars accelerating simultaneously. Then, taking $N = 8$, and $p_a = 0.15$ (nearest value to 0.133), go to Table IV and find $P_4 = 0.018$.

Now each car accelerates 11 times in each trip, or every $t = 15$ sec. Therefore, all the cars accelerate 480 times in, say, 15 min. Then $0.018 \times 480 = 8.64$ times in 15 min., or approximately every 2 min., a peak of $4 \times 267 = 1068$ amp. may be expected.

(14). Assume four cars running simultaneously at maximum speed. Then, for $N = 8$ and $p_m = 0.25$ find $P_4 = 0.0867$. Since all the cars reach maximum speed 480 times in 15 min., $0.0867 \times 480 = 41.6$ times, or approximately every 22 sec., the input may be expected to reach $4 \times 108 = 432$ amp.

(15). Assume that four cars accelerate simultaneously while the remaining cars are all running at maximum speed. Then $0.018 \times 0.0867 = 0.00156$ which is the probability of this condition, and may be expected $0.00156 \times 480 = 0.748$ times in 15 min., or once every 20 min. The resulting peak is 1500 amp. If the period of the assumed duty does not exceed 15 min. in a day, on the average this peak will not occur every day. However, the overload protective devices used must pass short peaks of at least this amount when also passing an r.m.s. current of 689 amp.

These probability calculations may be likened to casting eight sixty-sided dice of which $p_a = 0.133$ faces (8 faces) are marked "267 amp.," $p_m = 0.233$ (14 faces) are marked "108 amp.," and the remaining 0.633 faces (38 faces) are blank. The total amperes thrown in any throw is a probable point on the input-time graph (recording ammeter chart). A total of 432 amp. may be expected once in every 11.5 throws (480/41.6); a total of 1068 amp. may be expected once in every 54.3 throws; and a total of 1500 amp. may be expected once in every 640 throws.

In the next and concluding section of this article the method will be applied to elevator groups so as to set up tables of feeder sizes.

(To be continued)

A Portable Emergency Local Distribution Substation

By C. D. LIPPINCOTT
Assistant to Division Engineer, New York Power and Light Corporation

In order to minimize the time of service interruption to customers due to transformer burnouts or transformer changes, the Schenectady Electric Operating Department of New York Power and Light Corporation built a so-called "Portable Substation."

To prove or disprove the justification for and usefulness of the outfit, a $37\frac{1}{2}$-kv-a. distribution transformer was mounted on the chassis of an old electric truck, the front-axle assembly of which was rearranged for trailer operation. The result was crude and intended only as an experiment. It has answered the purpose so well, however, that it has remained in service. This substation is shown in Fig. 1. The sign on the side is self-explanatory and is effective in maintaining customer goodwill.

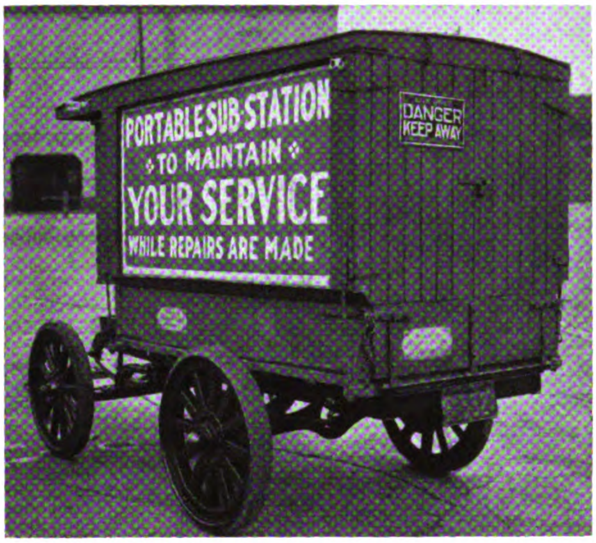


Fig. 1. Side View of the Portable Distribution Substation as it Appears Ready to be Drawn by a Truck to a Location Where Emergency Service is Needed

The reels shown in Fig. 2 provide a convenient means of carrying the primary leads while in transit and of disposing of slack, when in service. The end fastened to the reel protrudes enough to clamp in the cutout after the proper amount of slack has been taken up. The primary leads are No. 6 stranded, with 5/32-in. varnished-cambric insulation and weatherproof braid finish.

The secondary leads are carried coiled up in a cabinet in the front end of the substation, as shown in Fig. 3. They are of No. 2, stranded, rubber-covered cable. Both primary and secondary leads are terminated in "Tips No. 92 hot-line clamps," which provide a quick method of attaching them to the line with good electrical contact. A rod is provided with which to attach the clamps.

In addition to the kerosene tail light, there are four red 115-volt lamps located at the corners of the trailer and connected directly across one side of the transformer secondary. These serve as caution lights while the outfit is in service at the curb at night. Additional lamps to floodlight the signs would be effective, but have not been installed.

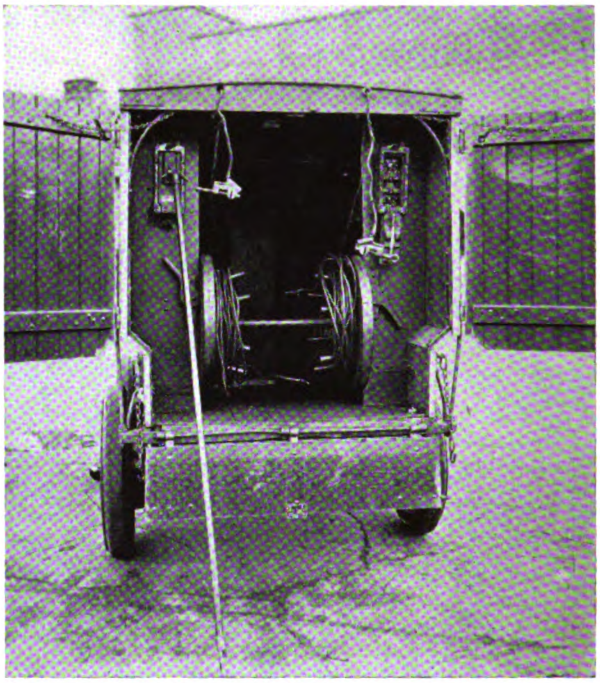


Fig. 2. Rear End of the Trailer Substation. The transformer is shown in the interior beyond the reels of the primary leads. The fuse cutouts and primary line clamps appear at the upper left and right

The substation is being used extensively for many purposes. After it was built, a rule was made that service must not be interrupted when replacing transformers. Instead, the crew assigned to changing the transformer takes along this portable substation, banks it in with the transformer to be changed, and proceeds with the work of replacement. The same applies to a power bank, if the pole is sound and the reason for the change is merely the need for increased transformer capacity. Of course if the pole must be replaced, new construction is used throughout and the completed job phased in with the old before removing the old equipment.

Occasionally a transformer fails—usually at night when only the night emergency man is immediately available. It is a quick and simple matter for him to restore service with the portable substation, and thus prevent the lengthy interruption that would be inevitable if a gang had to be organized at night to change the transformer. Customer goodwill (usually at a low ebb at such times) is obtained by such prompt restoration of service and the presence of the substation. Permanent repairs can be made the next day, without overtime, and after the distribution engineer has investigated the conditions and prepared proper repair orders.

The outfit is also very useful in providing increased capacity for such ceremonies as the opening of new municipal buildings, schools, etc., which have a large connected lighting load but low normal consumption.

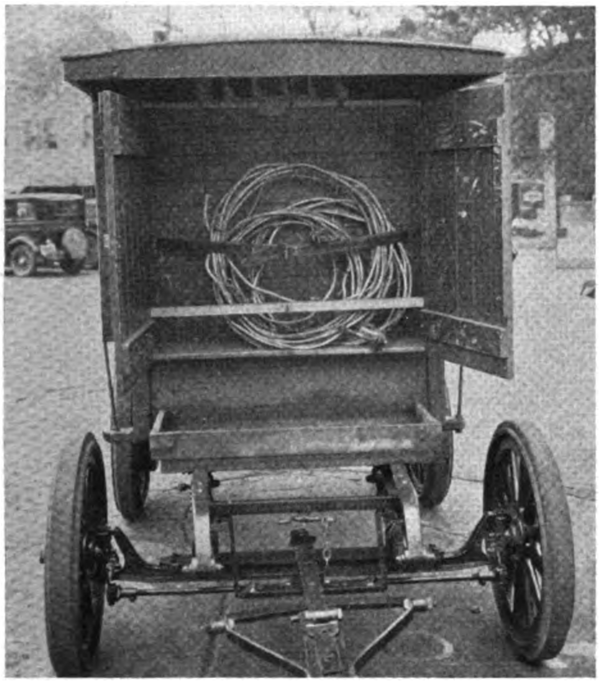


Fig. 3. Front End, Showing the Coils of Secondary Leads and the Front Axle Conversion to Trailer Operation

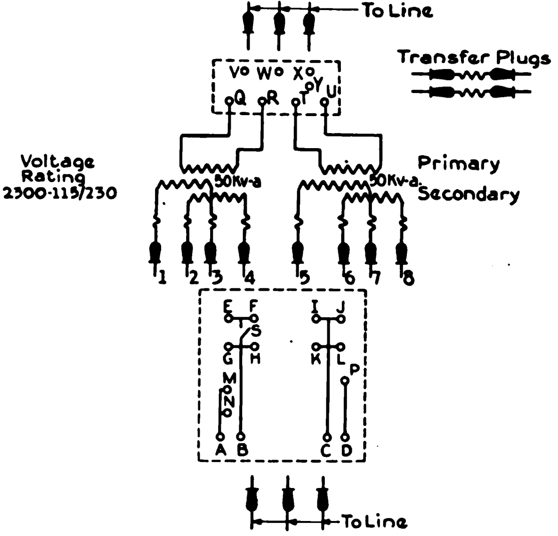
Schenectady is unique in having very few small power loads (requiring power banks up to three 25-kv-a. transformers) and hence there has been little need for three-phase emergency service. However the present outfit has so amply justified itself that it is planned to build a new portable substation comprised of two 50-kv-a. transformers with plug boards arranged so that the transformers may be connected series-multiple for thawing pipes, multiple for lighting, open-delta for 2300/230-volt three-phase power, or open-Y for 4000Y/230-volt single-phase power.

The proposed connections are shown in Fig. 4.

The outstanding accomplishment of the outfit is the possibility of giving quick and adequate emergency service. It can easily be justified solely on a customer-relations basis. It can also be justified financially. A complete portable substation, equipped with two 50-kv-a. transformers and accessories need cost no more than $1500, if mounted on an old truck chassis, which is adequate. The annual carrying charges on this investment at 16 per cent total $240.

Primary Connections

Use	Transfer Plugs		Line Leads to
Thawing	R to T,	U to Y	V and X
Mult. Ltg.	Q to T,	R to U	V and W
Pwr. (on 4 Kv. 4W.)	T to Y,	R to U	V and X with W = Neut.
Pwr. (on 2.3 Kv. Δ)	R to T,	U to Y	V, W and X



Secondary Connections

Use	Transfer Leads to Board									Line Leads to
	1	2	3	4	5	6	7	8	Sw's	
Thawing	E	G	I	K	F	H	J	L	Close	B and C
Mult. Ltg.	M	E	G	I	N	F	H	K	Close	A and C - B = Neut.
Power	M	E	F	I	J	G	H	P	Open	A. C. D.
Pwr. and Lt.	G	M	N	I	J	E	F	P	Open	B, C, D - A = Neut.

Fig. 4. Diagram of Connections of the Proposed New Substation That Will Have a Serviceability That is Much More Flexible Than the Present Substation

The outfit will earn annually approximately the following sums:

Annual revenue from pipe thawing	$100.00
Annual saving of line-gang labor in preparing for temporary loads, such as dedication ceremonies, etc. Line gang 1½ days (including truck)	100.00
Prevention of burnout and consequent saving of 50 per cent of the life of two 15-kv-a. transformers per year by prompt relief with the substation when a transformer is reported boiling over	130.00
Annual prevention of loss of revenue by quick restoration of service after burnouts	15.00
Annual elimination of overtime of gangs which would otherwise be called out to replace burnouts	75.00
Total	$420.00
Annual carrying charge on investment	240.00
Estimated Annual Saving	$180.00

Furthermore, most of the foregoing figures apply directly to the present single-phase outfit, in which there is an investment of only approximately $500.

Six years' experience with the present crude outfit has furnished a very convincing demonstration of its worth.

The Non-resonating Transformer

By **W. A. McMORRIS** and **J. H. HAGENGUTH**
General Transformer Engineering Department, Pittsfield Works
General Electric Company

The behavior of transformer windings under lightning voltage excitation is briefly analyzed. A new type of transformer is described, in which internal voltage oscillations are eliminated by the proper use of electrostatic shields. In this new type of transformer, all the desirable characteristics of the older type have been retained, and ability to withstand transient voltages has been greatly increased.—EDITOR

THE constantly increasing demand for reliability and for continuity of service in power transformers has made necessary constant study and research. The effectiveness of this study has been greatly aided by the development of the cathode ray oscillograph. Phenomena which could only be estimated in the past can now be accurately measured and studied at close range. As a result, the industry at large is beginning to appreciate the severe voltage stresses that may be produced in transformer windings by transient voltages.

Ordinary Transformer with Neutral Grounded Directly

In Fig. 1 is shown the cross-section of a comparatively high-voltage transformer coil stack of the concentric type. The coil stack consists of a helical low-voltage winding which is surrounded by a high-voltage winding of disk coils. In addition to the resistance, self inductance, and mutual inductance of these windings, there is capacitance from each turn to all others, and to the core and tank. For the sake of simplicity, we will assume the high-voltage winding to consist of a number of equal lumped inductances, each of which has capacitance to its neighbor and to ground, as shown in Fig. 2.

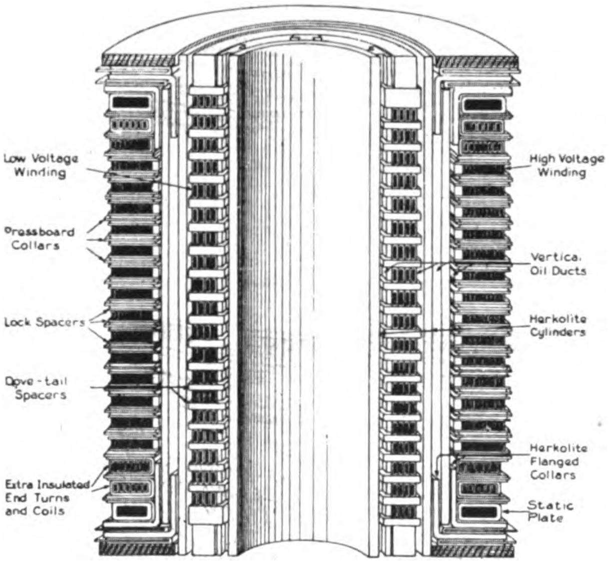
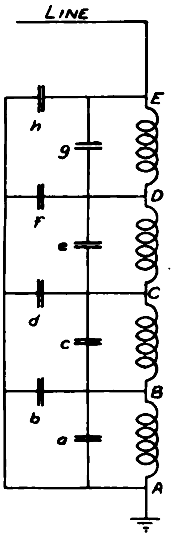


Fig. 1. Cross-section Through Windings of a Comparatively High-voltage Power Transformer

These values of capacitance are relatively small, and their effect is negligible at normal operating frequencies. If a voltage at normal operating frequency is applied to the winding, then it will distribute itself uniformly along the winding, since the distribution is determined by the uniform inductance of the winding.

The front of a lightning wave, which may rise from zero to maximum in a fraction of a microsecond, is in effect a quarter-cycle of very high frequency. The inductance of the winding offers a very high reactance to current at such a frequency, while the capacitance offers a low reactance. Therefore, the voltage distribution in this case is determined by the capacitance rather than the inductance of the winding.

The voltage distribution produced by the front of a lightning wave may be determined approximately by referring again to the equivalent circuit diagram in Fig. 2. It may be assumed that all the values of lumped capacitance are equal, and of such value that unit potential across them will cause unit current to flow. Then when the applied wave is such that the potential across a is 4, the current through a is 4. The potential and current for b are also 4. The current through c is 8, and the potential from A to C is 4+8 or 12.



	CAPACITANCE	VOLTAGE	CURRENT	% WINDING FROM GROUND	% VOLTAGE TO GROUND
h	1	84	84	100	100
g	1	52	52		
f	1	32	32	75	38.1
e	1	20	20		
d	1	12	12	50	14.3
c	1	8	8		
b	1	4	4	25	4.8
a	1	4	4		

Fig. 2. Equivalent Circuit of Ordinary Transformer

Continuing on through the circuit, it is found that the potential from A to E must be 84. Using these values of potential, a curve of initial voltage distribution may be plotted as shown in Curve *1* of Fig. 3. The results obtained by this method of calculation are numerically in error, because each coil is assumed to act as a solid metal plate, and no attempt is made to maintain the proper relation between coil-to-coil and winding-to-ground capacitances. However, this method clearly illustrates that the shunt capacitances b, d, and f are responsible for the non-uniform distribution of voltage along the winding.

If, after rising to its maximum value, the voltage of a lightning wave is sustained for a few microseconds or falls off gradually, this part of the wave is in effect low frequency, and tends to produce uniform voltage distribution as shown by Curve *2* of Fig. 3. In passing from the *initial* to this *final* distribution, the voltage over-shoots and goes through a series of oscillations about the line of final distribution as an axis.

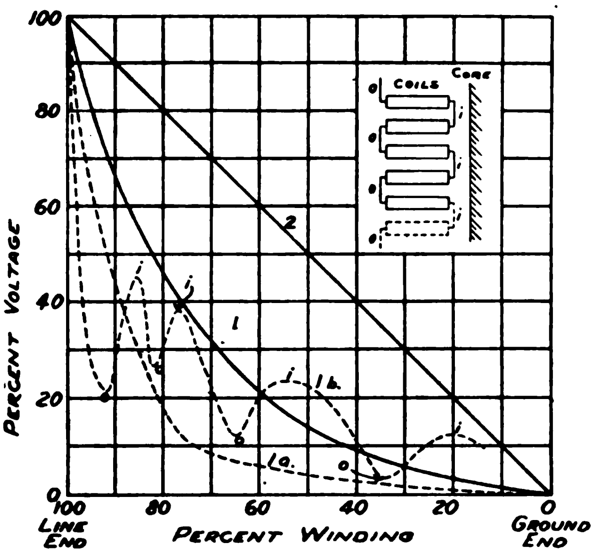


Fig. 3. **Initial and Final Voltage Distribution of Directly Grounded Transformers and Approximate Equivalent Circuit**

1—Initial, approximate equivalent circuit (calculated)
1a—Initial, core-type transformer (test results)
1b—Initial, shell-type transformer (test results)
2—Final, transformers and approximate equivalent circuit

Curve *0* of Fig. 4 is a typical curve of initial voltage distribution obtained by test. Curves *3*, *6*, *12*, and *18* show the calculated distribution *3*, *6*, *12*, and *18* microseconds later. The points shown on these curves were taken from test data. The dotted curve is the envelope of the maximum voltages to ground that appear during oscillation. It will be observed that this maximum is greater than the applied wave, even at points considerably removed from the line end of the winding. The steepness of the curves indicates the voltage gradient along the winding, and the stresses from turn to turn and from coil to coil. During the oscillation, very high turn-to-turn stresses appear at points throughout the winding.

Non-resonating Transformer with Neutral Grounded Directly

It has long been realized that if transformers could be so designed that the initial and final voltage distribution were the same, there would be no internal oscillation, and stresses produced by transient voltages would be greatly reduced. Such a transformer would operate with much higher factors of safety than the ordinary transformer.

From the calculation of the initial voltage distribution shown in Fig. 2, we can see that the unequal distribution is due to the charging currents which flow through the shunt capacitances b, d, and f to ground, and cause unequal currents to flow through the series capacitances a, c, e, and g.

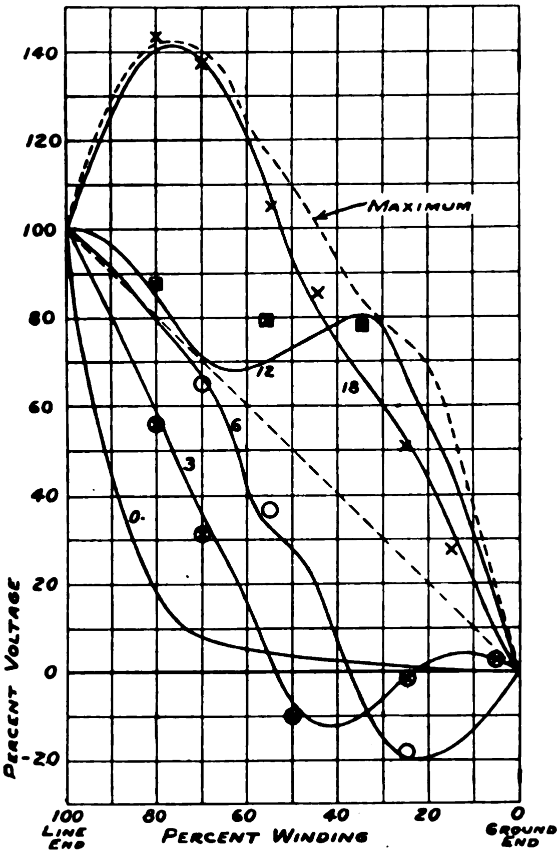


Fig. 4. **Voltage Distribution Produced in an Ordinary Transformer by a Single Traveling Wave**

0—Initial distribution
3—Distribution after 3 microseconds
6—Distribution after 6 microseconds
12—Distribution after 12 microseconds
18—Distribution after 18 microseconds
The curves are calculated, and the points taken from test data.

No changes that could be made economically in the proportioning or arrangement of coils or grounded parts could make an appreciable change in the initial voltage distribution. Impulse tests conducted over a period of years show that substantially the same conditions exist in all unshielded power transformers, whether of core-type or shell-type construction. Fig. 5 shows the voltage oscillations produced by a single traveling wave at several points of a core-type transformer winding, and Fig. 6 shows the same for a shell-type transformer winding.

The shunt charging current cannot be eliminated, but its effect on voltage distribution can be eliminated if an arrangement is used in which this current is not supplied through the impedance of the winding. In the non-resonating type of transformer developed at Pittsfield, charging current is supplied directly to the winding through conducting surfaces or shields located outside the winding and connected to the line terminal.

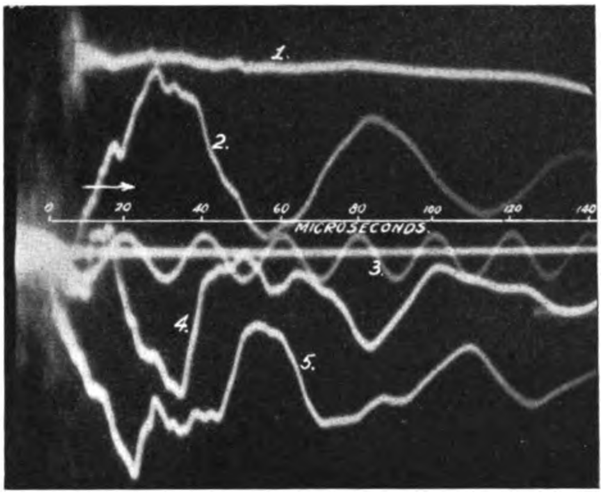


Fig. 5. Internal Voltages in Core-type Transformer

1—Applied wave
2—Voltage 50 per cent from ground end
3—Timing wave
4—26 per cent from ground end
5—78 per cent from ground end
4 and *5* were obtained with reversed polarity

The simplified equivalent circuit of this transformer is shown in Fig. 7. The capacitance from the shield to winding is represented by the lumped capacitances *i*, *j*, and *k*. If a voltage wave with steep front and a potential of 84 from *A* to *E* is applied as in Fig. 2, the potential from *A* to *B* must be 21, if the voltage distribution is to be uniform. The current through *b* will be 21, and must be equal to that through *i*. Since the potential across *i* is 63, the capacitance of *i* must be 1/3. Similarly it is found that the capacitance of *j* must be 1, and of *k* must be 3. The current through each of the series capacitances *a*, *c*, *e*, and *g* is 21, and the applied potential divides uniformly across them.

This distribution will be the same whether the applied wave is unidirectional with steep or sloping front, or is a sustained or damped oscillation of any frequency. In any case the initial and final distribution of the wave throughout the winding will be the same, and no internal oscillation can occur. The usual commercial high-potential and induced-voltage tests will be true measures of the ability of such a transformer to withstand voltages met in service, which is not the case with transformers of the ordinary type. The great reduction of voltages from winding to ground near the ground end makes it safe to grade the major insulation somewhat in the order of normal operating voltage stresses.

Curve *3* of Fig. 8 shows the voltage produced by a traveling wave at a point 63 per cent from the grounded end of a non-resonating transformer winding. The shape of this curve is practically a duplicate of that of Curve *2*, which shows the applied wave, and the amplitude is proportional to the distance from the grounded end of the winding. This clearly illustrates that non-uniform voltage distribution and internal oscillations have been eliminated.

Fig. 9 shows a 37,000-kv-a. (equivalent capacity) 220,000-Y-volt single-phase three-winding non-resonating transformer. In this type of transformer the insulating material is stressed uniformly, and factors of safety are much higher than in the ordinary type.

The shields used in non-resonating transformers consist of smooth metallic surfaces, properly insulated, and located outside the high-voltage winding. They do not interfere in any way with the mechanical construction of the transformer, making it possible to retain all the desirable features of the older type of design, such as ease of assembly and handling, free oil circulation, and ability to withstand short-circuit stresses.

Ordinary Transformer with Neutral Isolated or Grounded Through Impedance

Single Traveling Wave

While the majority of existing very high-voltage power transformers are operated with the neutral solidly grounded, there recently appeared a demand for grounding the neutral through inductance or resistance or for leaving the neutrals of some of the banks in the system isolated.

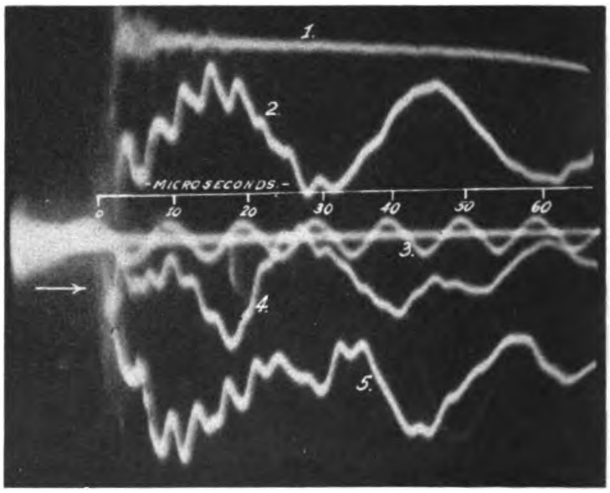
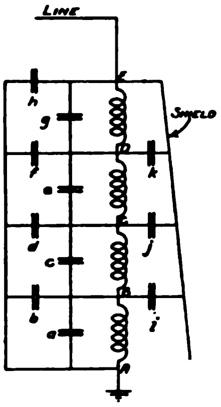


Fig. 6. Internal Voltages in One-group Shell-type Transformer

1—Applied wave
2—Voltage 50 per cent from ground end
3—Timing wave
4—26 per cent from ground end
5—78 per cent from ground end
4 and *5* were obtained with reversed polarity.

With the neutral isolated, the initial voltage distribution produced by the steep front of a single traveling wave is practically identical to that with the neutral grounded (see Fig. 10 *A* and *E*). The final voltage distribution is a straight line through the 100 per cent point parallel to the abscissa (Fig. 10 *E*).

The transition from the initial to the final distribution is effected through a damped oscillation of complex nature about the line of final distribution. The amplitude of the oscillation is determined by the difference between initial and final distribution and by the frequencies of the component harmonics. Owing to this oscillation, voltages to ground as high as 200 per cent of the applied voltage may appear at different points of the winding. Very high stresses also appear between various parts of the winding (Fig. 10 *E* and Fig. 11).



	CAP.	VOLTAGE	CURRENT	% WINDING FROM GROUND	% VOLTAGE TO GROUND
k	3	21	63		
j	1	42	42		
i	$\frac{1}{3}$	63	21		
h	1	84	84	100	100
g	1	21	21		
f	1	63	63	75	75
e	1	21	21		
d	1	42	42	50	50
c	1	21	21		
b	1	21	21	25	25
a	1	21	21		

Fig. 7. Equivalent Circuit of Non-resonating Transformer

The amplitudes and character of the oscillations in a transformer winding grounded through an impedance depend on the relative value of the impedance. With high impedance, the oscillation is similar to that of a transformer with isolated neutral. With low impedance, the oscillation is similar to that with neutral grounded directly (see Fig. 12 and Fig. 13).

In case the neutral of a transformer is grounded through a reactor, the "final voltage" at the neutral, *i.e.*, the voltage which would be obtained after application of an infinitely long traveling wave, is equal to $\frac{L_2}{L_1+L_2}$ times the applied voltage (where L_1 is the effective inductance of the transformer, and L_2 the inductance of the current-limiting reactor). In case the neutral is grounded through a resistor, the "final voltage" is equal to $\frac{Z_2}{Z+Z_2}$ times the applied voltage (where Z is the surge impedance of the line, and Z_2 the resistance of the grounding resistor). The line of final voltage distribution, or axis of oscillation, is a straight line connecting the point of "final voltage" at the neutral with the point of "final voltage" at the line terminal which is the applied voltage.

Switching Surges

The maximum amplitude of a damped oscillation, such as a switching surge, arcing ground, etc., is generally appreciably smaller than that of lightning. However, the voltage stresses produced by them in the transformer winding may be as high as those produced by lightning. This occurs because the damped oscillation applied to the transformer builds up internal stresses successively with each half cycle, when the frequency of this applied oscillation (Fig. 14) approaches one of the natural frequencies of the transformer.

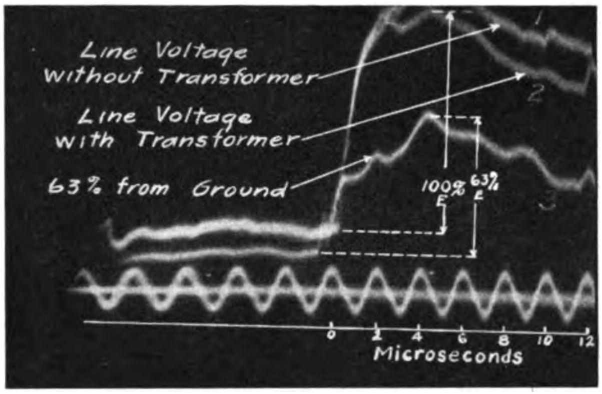


Fig. 8. Internal Voltage in Non-resonating Transformer

1—Voltage at end of transmission line with transformer disconnected
2—Voltage at end of transmission line with transformer connected (voltage across transformer)
3—Voltage at 63 per cent point from ground end. Crest value 63 per cent of applied voltage

NOTE—No. 3 is a practical duplicate of the shape of No. 2 in spite of the fact that the transformer was out of oil, and electrostatic unbalance created thereby.

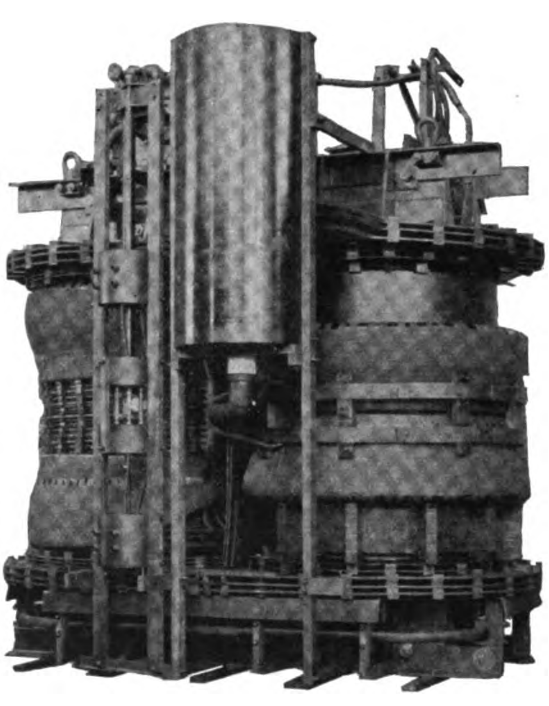
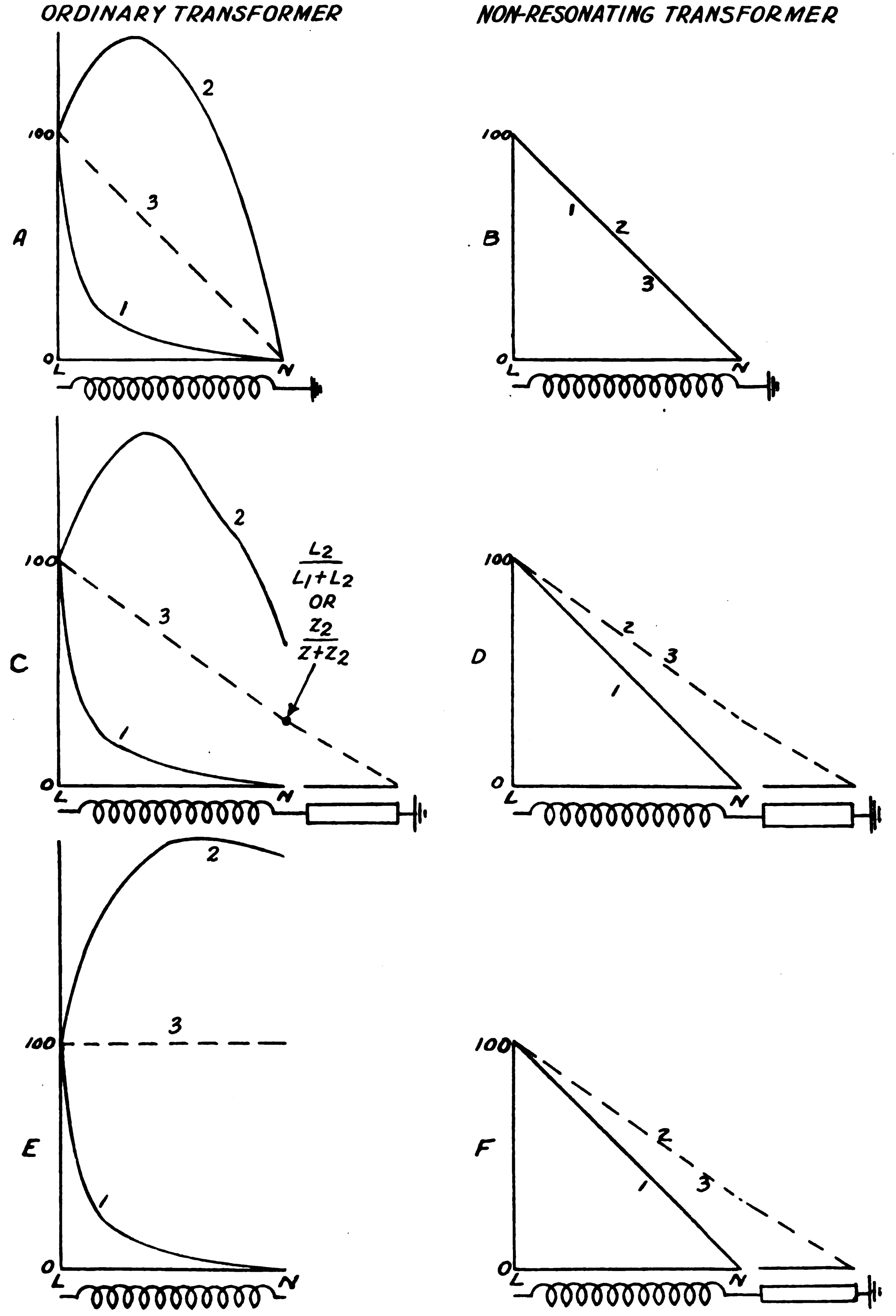


Fig. 9. 220,000-volt 37,000-kv-a. (Equivalent Capacity) Three-winding Non-resonating Transformer. 500,000-volt Insulation Test



ORDINARY TRANSFORMER

NON-RESONATING TRANSFORMER

Fig. 10. Summary of Effect of Variation of Neutral Impedance from Zero to Infinity on Internal Transient Voltages Produced in an Ordinary Transformer and a Non-resonating Transformer by Traveling Waves Met in Service

A and *B:* Neutral grounded directly

C: Neutral gounded through resistor or reactor

D: Neutral grounded through impedor (Capacitor and special resistor with neutral grounding resistor or reactor)

E: Neutral isolated

F: Neutral grounded through impedor (capacitor and special resistor)

1—Initial voltage distribution *2*—Envelope of maximum voltage to ground *3*—Final voltage distribution

Non-resonating Transformer with Neutral Grounded Through Impedance

Two methods are available to obtain a non-resonating type of transformer under these grounding conditions: one is to shield the winding in such a way that the initial voltage distribution coincides with the final

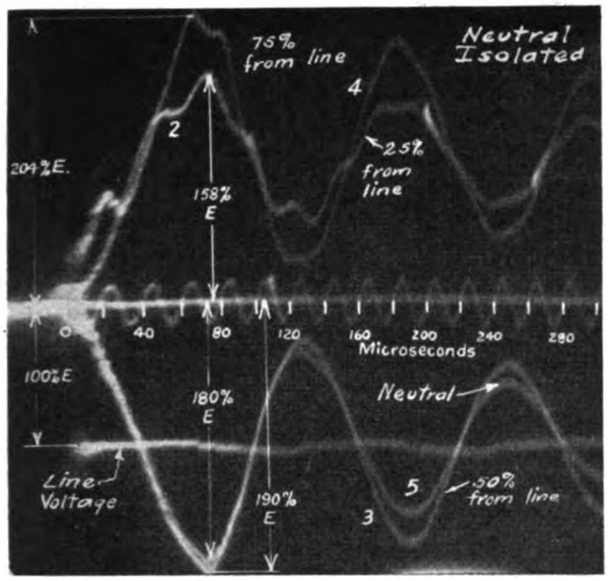


Fig. 11. Oscillations in a Shell-type Transformer with Isolated Neutral

1—Voltage at line terminal
2, 3, 4, and *5*—Voltages to ground at points 75, 50, 25, 0 per cent away from neutral terminal with crest values of 158, 190, 204, 180 per cent of applied voltage respectively

Note—All voltages recorded below zero line are taken with reversed polarity.

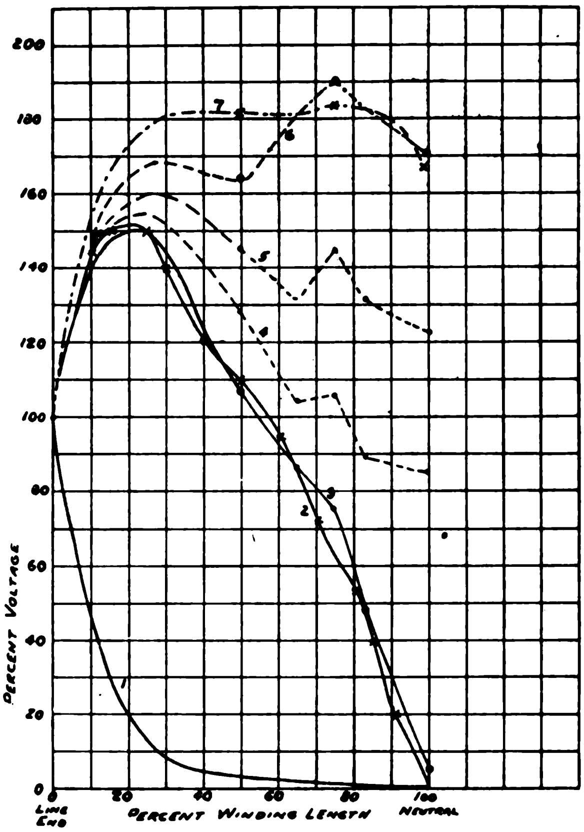


Fig. 12. Effect of Magnitude of Neutral Resistance on Internal Transients of Transformers (Test Results)

1—Initial voltage distribution
2, 3, 4, 5, 6, and *7*—Maximum voltages to ground for different resistances in the neutral
2—$R = 0$ (solidly grounded neutral)
3—$R = 500$ ohms
4—$R = 5000$ ohms
5—$R = 25{,}000$ ohms
6—$R = 100{,}000$ ohms
7—$R =$ Infinite (neutral isolated)

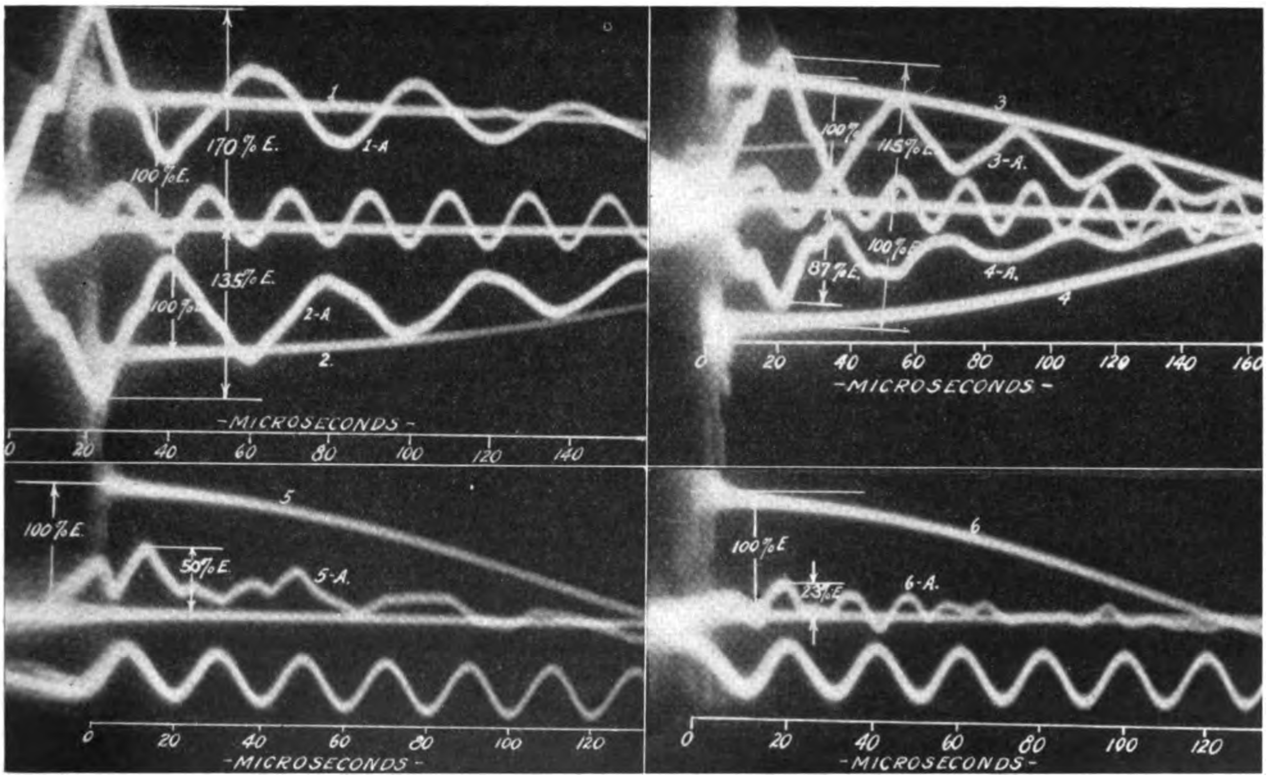


Fig. 13. Effect of Inductance on Neutral Oscillations

1, 2, 3, 4, 5, and *6*—Voltages at line terminal
1A, 2A, 3A, 4A, 5A, and *6A*—Voltages with neutral to ground with different ratios of neutral inductance to transformer inductance

Ratio $\frac{Ln}{Ln+Lt}$	Curve:	*1A*	*2A*	*3A*	*4A*	*5A*	*6A*
	Ratio:	1	0.725	0.67	0.48	0.26	0.097

distribution. The other is to use a standard non-resonating transformer and by means of an impedor keep the neutral at practically ground potential during the period of high-frequency transient. The first method of shielding is very costly in the case of isolated neutral or high neutral impedance. The second method therefore is generally employed.

The impedor in general comprises a capacitor and a special resistor in parallel with a neutral-grounding reactor or resistor. The value of the grounding reactance or resistance depends entirely on the operating frequency requirements, such as limitation of short-circuit currents. The function of the special resistor is to prevent the possibility of resonance of the neutral capacitor with the rest of the system in case of damped oscillation.

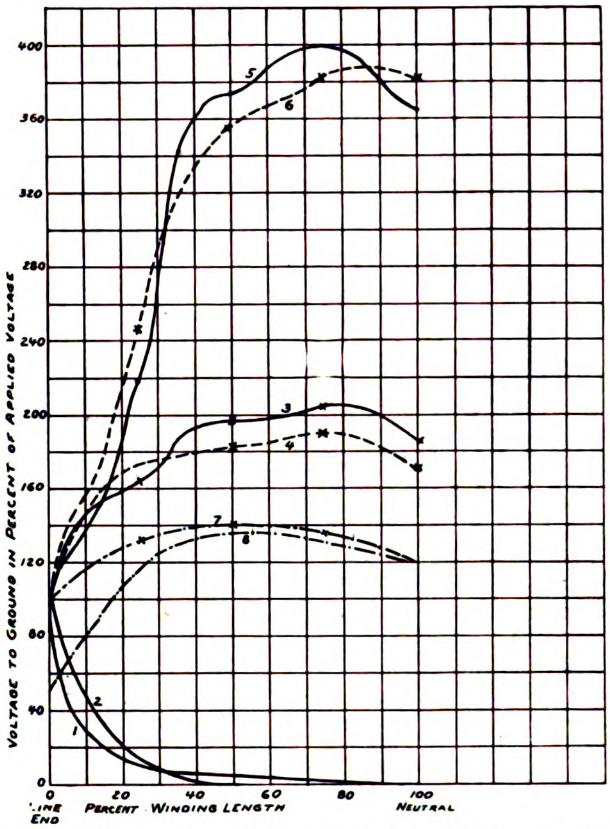


Fig. 14. Voltage to Ground in Shell and Core-type Transformers, with Isolated Neutral, Due to Lightning and Switching Transients (Test Results)

1 and *2*—Initial voltage distribution
3 and *4*—Maximum voltage to ground due to lightning
5 and *6*—Maximum voltage to ground due to switching
(*1*, *3*, and *5* refer to shell type; and *2*, *4*, and *6* to core-type transformers)
7—Estimated voltages met in practice, due to lightning
8—Estimated voltages met in practice, due to switching (applied voltage equal to 50 per cent of lightning voltage)

When a non-resonating transformer grounded through an impedor is subjected to a single traveling wave, the initial voltage distribution in the transformer winding is uniform, the same as when the neutral is grounded directly (see Fig. 10 *B*, *D*, and *F*). Then the voltage throughout the winding starts to rise like a rigid rod toward the line of final voltage distribution, which in this case is dependent on the characteristics of the special resistor and the other constants of the impedor. By choosing a capacitor of the proper value, the rate of neutral voltage rise can be made extremely slow compared to the length of

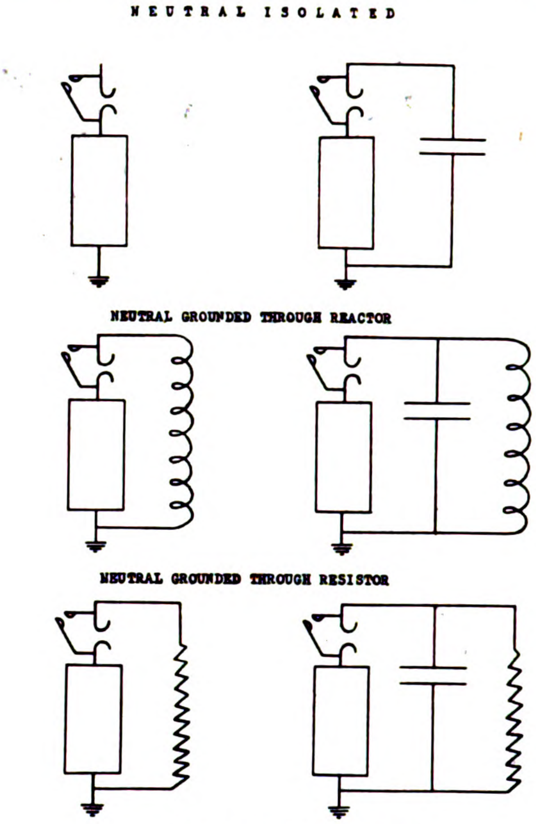

NEUTRAL ISOLATED
NEUTRAL GROUNDED THROUGH REACTOR
NEUTRAL GROUNDED THROUGH RESISTOR

Fig. 15. Impedor Circuits

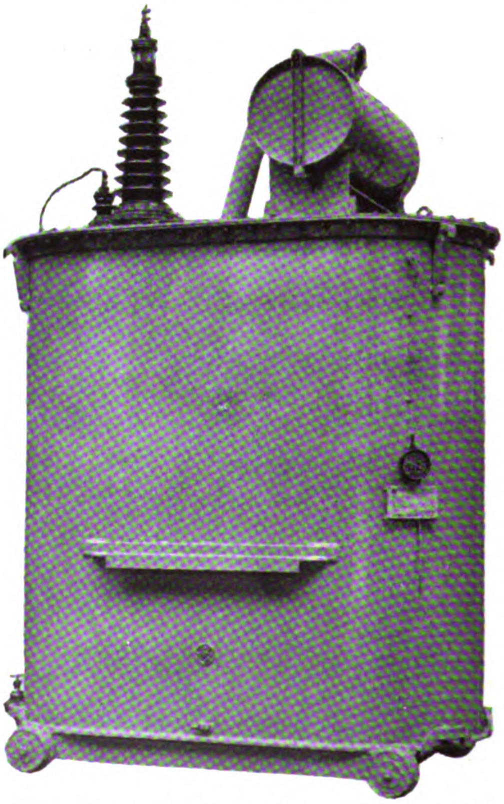


Fig. 16. Impedor for Bank of Three 25,000-kv-a. 220-kv. Non-resonating Transformers

the traveling wave. Therefore, the neutral remains substantially at ground potential during the transient.

The maximum voltage at the neutral can be easily and accurately calculated, and can be limited to any desired value. Therefore the only determining factor for the insulation of the neutral from ground is the operating frequency stress obtained when one line is short-circuited to ground. The insulation at the neutral can be reduced to correspond to a high-potential test of twice this voltage, and the insulation of the remainder of the winding can be graded proportionately.

Fig. 15 shows impedor connections for various requirements. The box shown indicates a special type of resistor which may be connected to the neutral of the transformer either through a gap, or directly.

An impedor can be designed to ground the neutral of either one bank or several banks connected in parallel. Fig. 16 shows an impedor for use with a bank of three 25,000-kv-a. 220-kv. transformers of the non-resonating type. This impedor contains a neutral-grounding reactor, a capacitor, and special resistor.

There are now in operation or under construction a total of approximately two and a half million kv-a. of non-resonating transformers. About half of the installations will operate with the neutral grounded through an impedor.

Conclusions

In concluding we may summarize as follows:

(1). When an ordinary directly grounded transformer is subjected to a lightning wave, violent oscillations occur throughout the winding. These oscillations are more severe when the transformer is isolated or grounded through impedance. In either case, very high stresses appear between parts of the winding and between the winding and ground. High stresses to ground appear even near the neutral, making it extremely dangerous to grade the insulation from the high-voltage winding to the low-voltage winding and ground.

(2). These oscillations are eliminated in the non-resonating transformer by the use of properly proportioned electrostatic shields, supplemented by the use of an impedor where the neutral is grounded through an impedance.

(3). By eliminating internal oscillations, the winding-to-ground stresses are reduced in some cases to one-sixth the value in the ordinary transformer. Stresses between certain other parts of the winding may be reduced to one-hundredth.

(4). The reduction of turn-to-turn and coil-to-coil voltages results in reduction of stresses at ratio adjusters, terminal boards, and other connected devices.

(5). Customary high-potential and induced-voltage tests are true measures of the ability of non-resonating transformers to withstand conditions met in service, which is not the case with ordinary transformers.

(6). Non-resonating transformers retain all the desirable characteristics of the older type of transformer.

The authors wish to express their indebtedness to Mr. K. K. Palueff for his helpful suggestions in the preparation of this article.

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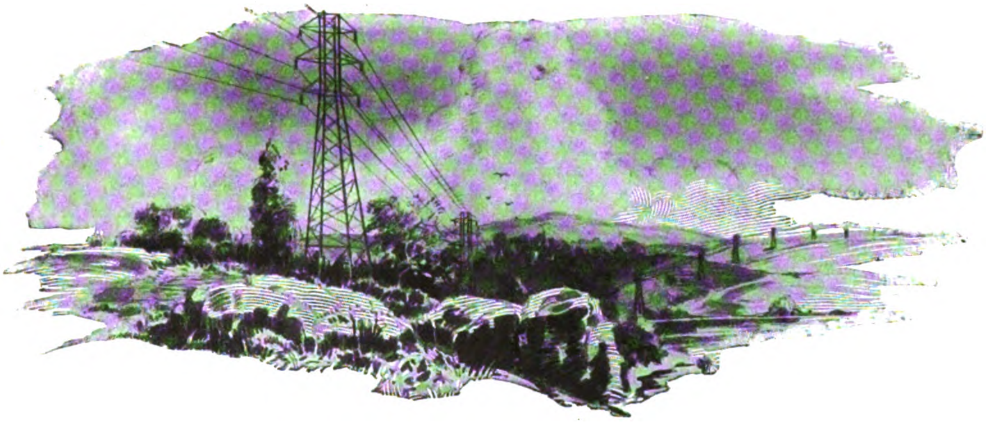

A New Form of Stroboscope

By **R. G. STANDERWICK**
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General Electric Company

IT is interesting to follow some of the developments of applied physics back through the ages, and perhaps one of the most interesting is that of a prism. For many centuries pieces of glass or stones were cut so they would sparkle in the light, and about the only use found for them by the ancients was that of ornamentation.

It was many years after cut-glass had been used for ornaments that an actual prism was made; and its value, of not only reflecting, but also of dispersing the sun's rays, was studied. Our prisms for analyzing the solar spectrum and the like followed. The value of a prism as a reflecting medium without the use of a silvered surface was appreciated and used in a great number of cases.

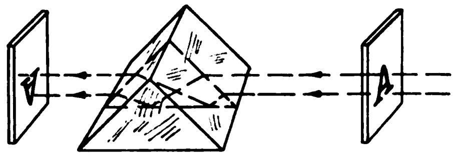

Fig. 1

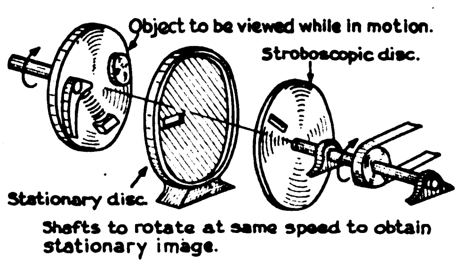
Object to be viewed while in motion.
Stroboscopic disc.
Stationary disc.
Shafts to rotate at same speed to obtain stationary image.

Fig. 2

One of the later uses of the prism is to erect images, which have been inverted by means of magnifying lenses. The laws of a prism for inverting images are very simple and are portrayed in Fig. 1.

Optical instrument manufacturers, for the most part, use such prisms in great numbers, but quite recently an additional value has been placed upon the prism, in which the inverting characteristics are applied to a new use.

In the analysis of motion in a piece of machinery which is moving, many forms of stroboscopes are used. There was, in the first place, the stroboscope disk driven at a rate corresponding to the rate of motion of the machine which was to be studied (see Fig. 2). A momentary glimpse of the machine which was very highly illuminated was made possible each time the slot passed between the eye and the object, and though the interval of time was of very short duration, yet the persistence of vision, with which we are all handicapped, helped in this case to carry the picture over until the slot had made one complete revolution and then replenished our vision.

It is well known that by changing the relative position of the slot to the machinery in motion that any part of the cycle may be studied, but we are only given a chance to study this at one point of the cycle at a time.

By the aid of a Neon lamp very high intensity flashes of extremely short duration cause the moving machinery to be illuminated, and to work upon the same principle as the rotating disk (Fig. 3).

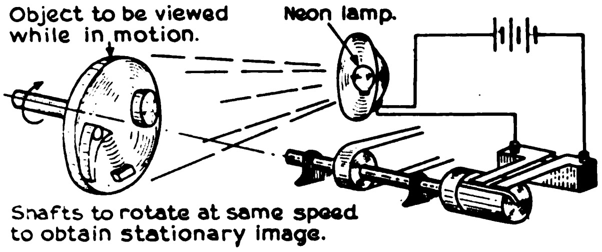
Object to be viewed while in motion.
Neon lamp.
Shafts to rotate at same speed to obtain stationary image.

Fig. 3

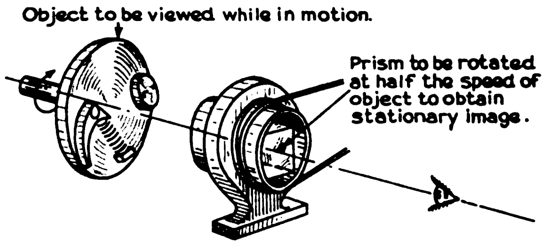
Object to be viewed while in motion.
Prism to be rotated at half the speed of object to obtain stationary image.

Fig. 4

This form of stroboscope or, as it is sometimes called, oscilloscope, is in general use, but here again only one point at a time may be studied.

By the use of the ultra-rapid moving picture camera, photographs taken for several positions during one cycle are possible, but this requires expensive equipment, and the analysis of the pictures so obtained is a somewhat complicated and tedious procedure.

The value of any of the foregoing devices depends, therefore, upon whether they are used to observe the action of a piece of mechanism which is performing a series of operations in which the cycle is complete either in one or a definite number of revolutions, and in which the cycle is repeated.

In dealing with mechanisms in which the cycle is not repeated it is necessary for a continuous vision of the device to be obtained. Such a mechanism has been developed as a high-speed emergency-tripping means for steam turbines and the like, a typical example of which is the bolt type, ring type, or modifications of these two.

Here it is important that at a certain speed the mechanism will become unstable and suddenly snap from its set position to the tripping position. It must not creep out slowly. Furthermore, it should reset at some definite speed with a snap.

In order, then, to watch the action of such a device a relatively large erecting prism was mounted inside the inner race of a large ball bearing, in such a way that the center of the field of vision in the erecting portion was concentric with the axis of rotation of the prism.

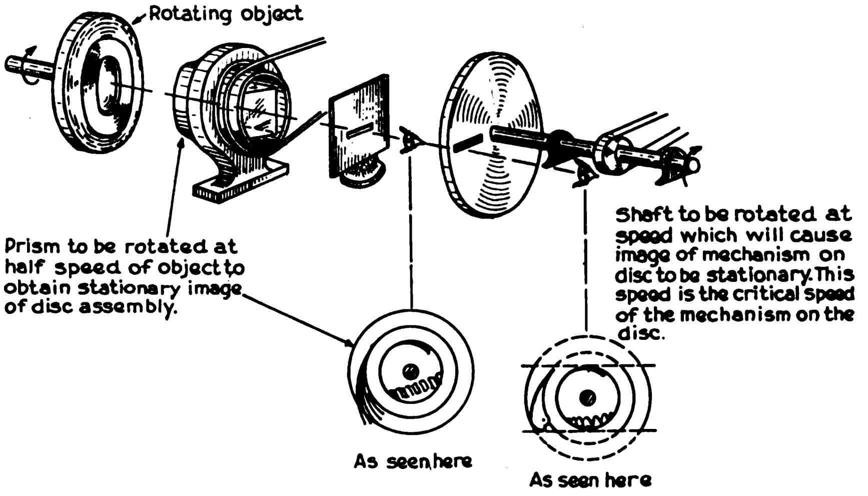
Rotating object
Prism to be rotated at half speed of object to obtain stationary image of disc assembly.
Shaft to be rotated at speed which will cause image of mechanism on disc to be stationary. This speed is the critical speed of the mechanism on the disc.
As seen here
As seen here

Fig. 5

If we now study what goes on in the erecting field of this prism we shall see that if we are looking at some printed matter through the prism, and then rotate it slowly, the printing travels around at a rate twice as fast as we rotate the prism; and the rotation of the printing is in the same direction as the rotation of the prism.

If we now revolve the printed matter at exactly twice the rate at which we rotate the prism we shall find that the printing remains at rest. We, therefore, arrange to drive the prism that is mounted to the inside of a ball bearing, at a rate of exactly one-half the rate of rotation of the emergency disk, and in this way we bring the mechanism visually to rest, and have the privilege of watching it all the time, no matter what the speed of the disk may be (see Fig. 4).

There are other types of devices such as the centrifugal starting switches for motors, and the like, which should be designed correctly with the same snap action characteristics. Unless the design has been carefully worked out, it is quite possible that the mechanism does not snap out but hesitates or vibrates a little; and if this vibration is persistent then means are available of analyzing the frequency of vibration. In this case the switch disk may be brought to rest visually by means of the rotating prism and then the frequency of vibration determined by a stroboscope disk driven at various known. speeds by a variable speed motor. In this way complete action of the mechanism may be readily determined and the design changed to eliminate the undesirable features.

Thus we have found a new use for a piece of cut glass. One can readily see many applications of such a scheme, for example, in watching the action of a valve gear on rotating airplane engines, or by reversing the action, the production of weird kaleidoscope effects by the proper selection of colored lights and the like.

Brazing by Resistance Method

Equipment Required—Handling Capacity—Preparation of Joints—Technique of Brazing Operation

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MANY metals such as copper, nickel, silver, steel, and their alloys can be brazed electrically. This type of brazing has been perfected in the Pittsfield Works Laboratory of the General Electric Company and has been used extensively in production work for about two years. The process makes use of the high resistance of carbon blocks to the flow of electricity, and the equipment required is simple and inexpensive. The pieces to be joined are clamped between a pair of carbon blocks and current is passed through the carbon blocks and the joint. The carbon electrodes heat up quickly and the heat passes from them into the metals being joined. A thin strip of brazing alloy is applied at the contact surface between the metals, and this alloy melts and flows through the joint section uniting the parts into a solid mass.

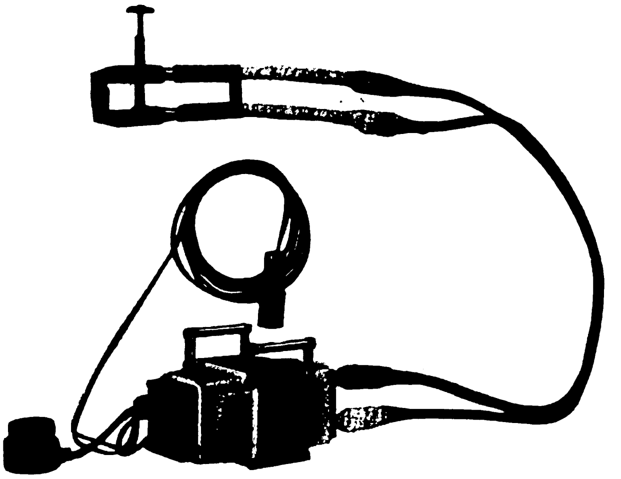


Fig. 1. Standard 10-kv-a. Brazing Transformer Complete with Tongs, Switch, Plug, and Cables

The brazing apparatus consists of an air-cooled transformer, foot switch, primary and secondary leads, and tongs for holding the carbon blocks. Either of two sizes of transformer may be used, depending upon the size of the materials to be joined. A 5-kv-a. transformer weighing 45 lb. is employed to braze cables, conductors, bars, etc., up to 300,000 cir. mils in cross-section. This transformer is wound with a 220-volt primary and an 8-volt secondary. A 10-kv-a. transformer weighing 95 lb. is required to make joints on parts having a cross-section between 300,000 and 2,000,000 cir. mils. The standard 10-kv-a. brazing transformer is wound for 220 volts on the primary and for 8, 10, and 12 volts on the secondary. These taps can be readily changed for different size joints, the higher taps being used for large sections. Both the 5-kv-a. and the 10-kv-a. transformers will carry a momentary overload of 400 per cent. The entire equipment is portable and can be applied to joints in any position. In some cases, it is more convenient to mount the 10-kv-a. transformer on a small truck.

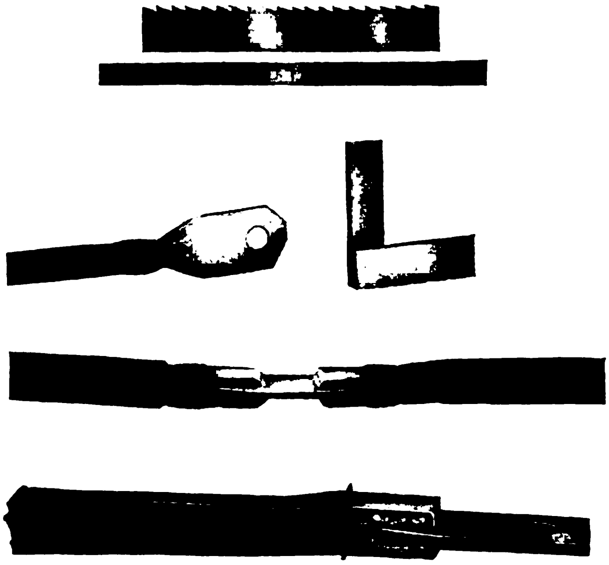


Fig. 2. Typical Brazed Joints

Steel Band Saw.
Butt Joint on ⅛-in. by ½-in. Copper Conductor.
Stranded Cable Brazed to Flat Terminal.
Two ¾-in. by 1½-in. Copper Bars Brazed at 90-deg. Angle.
Two Stranded Cables Brazed to Flat Plate.
Groups of Copper Braid in Clips Brazed to Flat Terminal.

Joints made up of material larger than 2,000,000 cir. mils are brazed in stationary machines or presses. Several types and sizes of tongs are used for applying the carbon blocks to various kinds of joints.

All surfaces to be brazed should be as flat as possible to insure good contact with the carbon electrodes, and thus prevent arcing and "hot spots." Round rods, solid wire, etc., should be flattened with a hammer, by milling, or in any other convenient manner, at the point where the joint is to be made. In special cases where the metals cannot be made flat, the carbons can be shaped to fit round or irregular surfaces. Tubular terminals are replaced by flat plates; and when the plates are more than one inch wide they are slotted to prevent excessive heat radiation during the brazing operation. Slots or saw cuts are made about one inch apart and each section between slots is brazed as a separate operation with the portable apparatus.

Stranded cable is either wrapped with thin copper strip or inserted in a thin copper tube and then flattened before clamping in the tongs. The wrapping or tube should extend on the cable ½ to 1 in. beyond the braze. The insulation on cable should be removed for a distance of ½ to 2 in. from the joint, depending upon the size of the cable, and the bare cable is wrapped with damp asbestos at the end of the insulation to protect it from overheating during the brazing process.

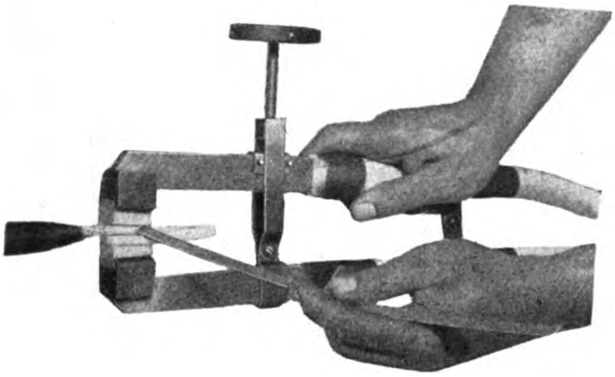


Fig. 3. Brazing Cable to Flat Terminal

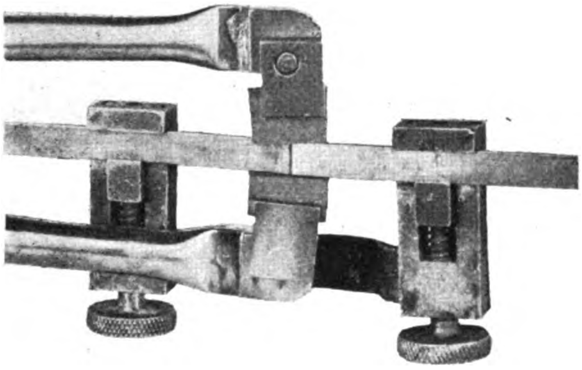


Fig. 5. Method of Applying Tongs to Edges of Conductor in Making Butt or Scarf Joint, Showing Conductors Held in Place by Steel Clamp

Copper braid should be enclosed in a copper clip about 0.020 in. thick and slightly wider than the braid. When several flat strips of braid are used in parallel, one clip is put over the end of the group and should extend on the braid about ½ in. beyond the contact surface. A thin piece of brazing alloy about ½ in. square is usually placed in the end of alternate braids throughout the group before clamping in the tongs.

In making a lap joint on cables, bars, etc., the length of lap should be about one and one-half times the thickness of the conductor. Butt joints on rectangular conductors are made by holding the two ends together in a suitable clamp, applying the carbon blocks to the edges of the conductor, and feeding the alloy in from the flat side. (See Fig. 5.)

It is not essential to clean the surfaces for brazing to the same extent that is done in soft soldering since the brazing flux removes the oxides and other impurities. Certain oils and varnishes, however, are not attacked by the flux and should be removed before brazing. Fused borax (sometimes called borax glass) is generally used as a flux, but in some cases it is more satisfactory to use potassium acid fluoride in paste form. The borax can be used in dry powder form, in water solution, or mixed with vaseline. Dry borax is usually more satisfactory and can be sifted from a small "talcum-powder" can or applied by a small powder bellows. Less flux is wasted in this way than when it is thrown on with the hands.

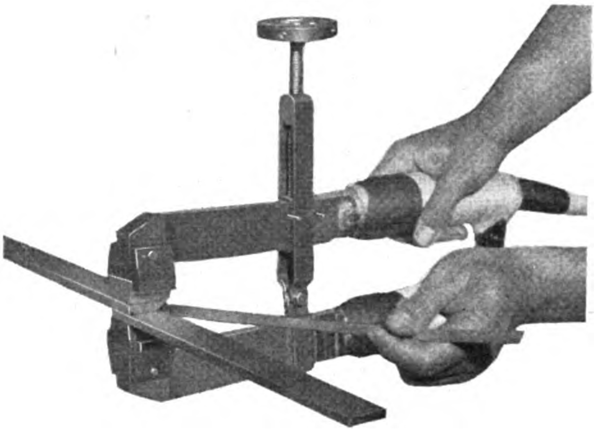


Fig. 4. Making Joint Between Two Brass Bars

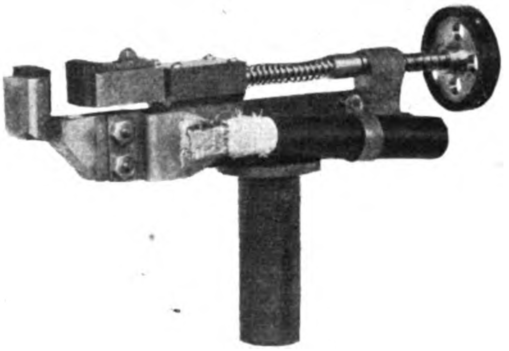


Fig. 6. Horizontal Type of Brazing Tongs

Three different silver alloys are used as brazing media, depending upon the type of joint being made. One of these alloys contains 50 per cent silver and has a melting point of 725 deg. C. (1337 deg. F.). The alloy containing 30 per cent silver melts at 735 deg. C. (1355 deg. F.); and the one containing 10 per cent silver melts at 830 deg. C. (1526 deg. F.). In order to protect the insulation and prevent the overheating of very small copper wire, it is essential to keep the brazing temperature at the acceptable minimum. For such work, the 50 per cent alloy is used; but on larger cables, conductors, terminals, etc., the 30 per cent alloy is generally used because it is less expensive. The alloy containing 10 per cent silver is best suited to brazing heavy bus bars, plates, and the like, where there is no insulation.

When the parts to be joined have been prepared as described, they are clamped between the carbon electrodes and pressure is applied by turning the handwheel. A small amount of flux is applied to the joint and the current is turned on by pressing a foot switch in the 220-volt circuit. Small sections of metal can be heated to brazing temperature in a few seconds. but large masses require more time and the current should be applied intermittently to allow the heat to distribute itself throughout the mass.

When the borax melts, a strip of silver solder is held against the hot metal at the line of contact between the parts being joined. The alloy melts and follows the borax throughout the joint. The proper length of time to leave the heat on is determined by the action of the flux. When the borax rises to the surface of the molten alloy, it is an indication that the heat is sufficient and the current can be turned off. Care should be taken not to remove the tongs or to release the pressure on them until the joint has cooled to a dull red.

In the process of brazing copper parts, the molten alloy dissolves a thin film of the metal surfaces and forms a new alloy rich in copper and having a melting point higher than that of the original silver solder. For this reason a higher temperature is always required to open such a joint than to make it. Lap joints are usually designed to have a contact area at least one and one-half times the cross-section of the conductor. The factor of safety of these joints is very high for they will carry as much overload as the conductor itself.

Joints made with silver solder or other high-melting-point alloys have several advantages over joints made with ordinary soft solder. In most cases a brazed joint can be made in from one-half to one-third the time required to make a lead-soldered joint on the same size conductor. On account of the saving in time and the small quantity of alloy used the brazed joint is invariably cheaper; and its mechanical strength, durability, and electrical conductivity are much higher than those of a soft-soldered joint. Brazed joints are considerably smaller and are easily accessible to inspection since all the work is open. When a tubular terminal is soldered to a cable, it is impossible to inspect the joint thoroughly, but a cable brazed to a flat terminal can easily be examined to see that there are no defects.

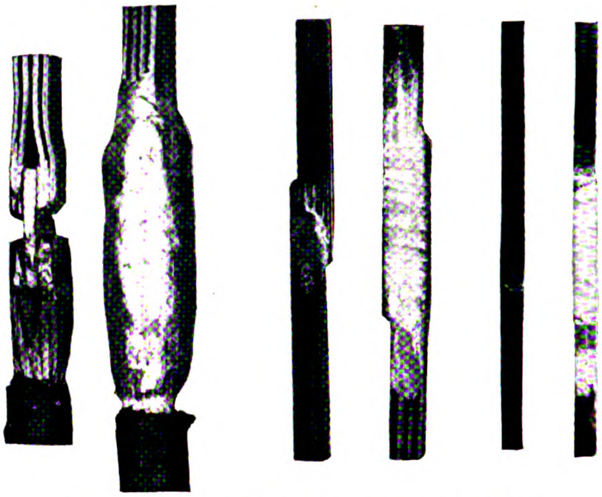
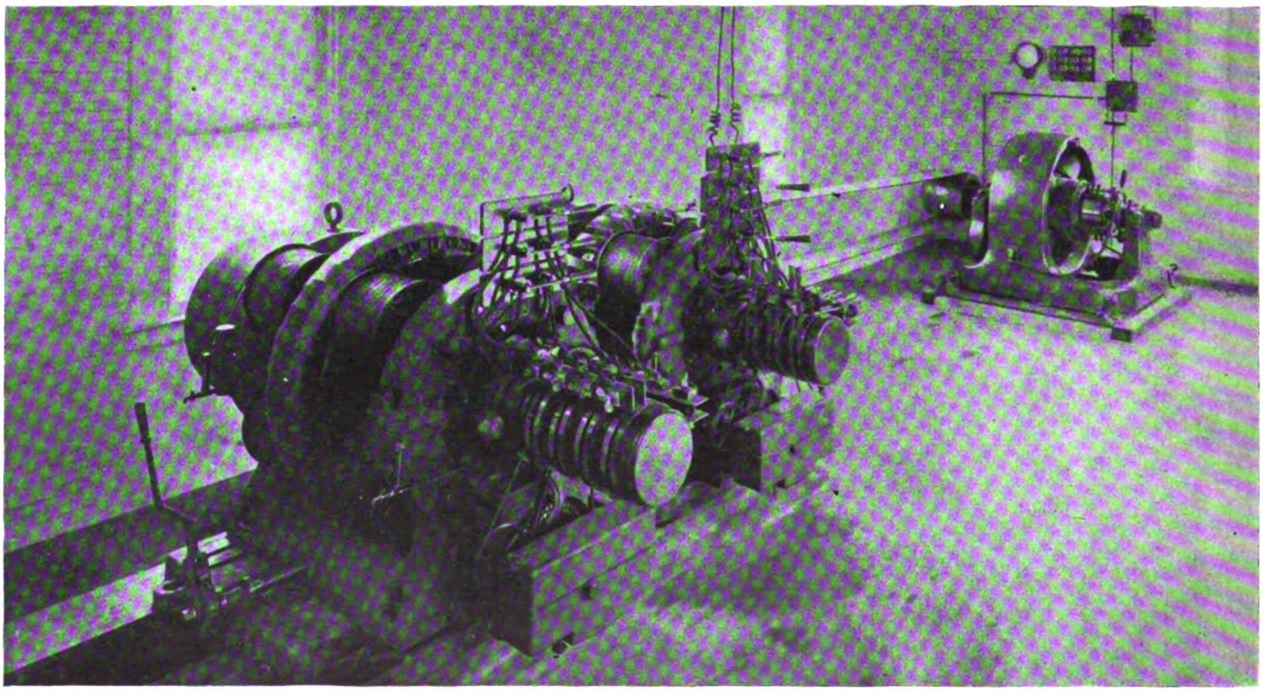


Fig. 7. Comparison of Sizes of Brazed and Soldered Joints

Historic Dynamos


The dynamos which operated the first public display of Magnetite arc lamps, when, in the spring of 1901, Steinmetz gave a demonstration of twenty-five of these lamps

Thyratron Stabilizer for X-ray Tubes

By **WILLIAM K. KEARSLEY**
Research Laboratory, General Electric Company

PRACTICALLY all modern x-ray tubes depend for their operation on the flow of electrons from an incandescent filament. X-rays are produced when these electrons impinge on the "target" or anode of the tube, the quantity of rays produced being directly proportional to the number of electrons reaching the target.

To maintain a constant current through the tube it is necessary, therefore, to maintain a constant electron emission from the filament. Two factors govern this emission; the temperature of the filament and the condition of its surface. If the surface is contaminated by a film of oxide or by adsorbed gas the emission will be reduced by an amount depending on the nature and extent of the contamination. If it were not for this surface effect it would suffice merely to keep the filament heating current constant in order to maintain a constant electron emission, and hence a constant output of x-rays from the tube.

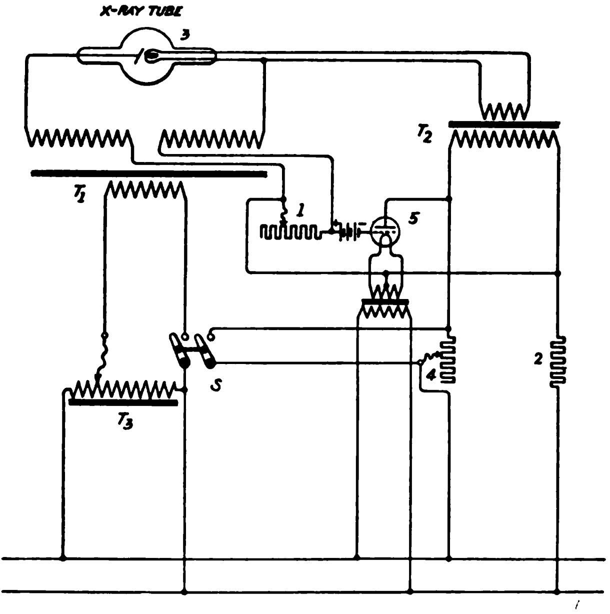


Fig. 1. Circuit Connections of X-ray Tube with Thyratron Stabilizer

In practice, the filament is usually heated by current from a small transformer connected to the supply mains, and it is customary to include in the circuit a variable impedance of some kind for control.

In its simplest form this control member is hand operated and must be frequently adjusted while the x-ray tube is in operation if a steady current is to be maintained. To relieve the operator of the necessity of making this adjustment to correct for line-voltage fluctuations, various stabilizing transformers have been developed to replace the usual filament transformer. The use of these transformers gave practically constant output over a range of line voltage and would have been satisfactory but for the effect of surface contamination.

About ten years ago another form of stabilizer was developed (1) which operated somewhat like the automatic voltage regulator for alternating-current generators. A pair of contacts were controlled by a magnet, the coil of which was in series with the x-ray tube. Any variation in tube current was immediately compensated for by cutting a resistance into the filament supply circuit by means of the contacts. This device gave good regulation and has come into very wide use. It was felt, however, that a stabilizer which had no moving parts and no contacts might be still better in that it would have nothing to get out of adjustment.

In Fig. 1, T_1 is a transformer supplying high voltage to x-ray tube *3*. T_2 supplies filament current and T_3 is an auto-transformer for adjusting the voltage at the tube; *5* is a small Thyratron tube. (2)

The current which passes through the x-ray tube *3* from transformer T_1 also passes through a resistance *1* which is in the grid circuit of the Thyratron tube *5*. There is a small biassing battery in this grid circuit which applies negative potential to the grid. Resistance *2* is low enough to allow more current to flow in the filament of x-ray tube *3* than will ever be needed.

On closing the switch *S*, the current through the x-ray tube *3* and resistance *1* rises rapidly until at some point in each cycle the drop in voltage across resistance *1* becomes equal to or slightly greater than the voltage of the battery. This brings the grid to zero voltage or makes it even slightly positive and the Thyratron tube *5* becomes conducting. The Thyratron tube then forms a short circuit across the filament transformer and, owing to the presence of resistance *2* in the circuit, practically shuts off the heating current supplied to the filament for the remainder of that half wave. Because the filament of an x-ray tube is of relatively large mass, its rate of heating and cooling is so slow that its temperature does not follow these periods of high and low heating current but remains nearly constant at that intermediate value that is just sufficient to supply the proper load current to the tube. If this current should tend to increase or decrease during the operation of the tube, the average filament temperature is lowered or raised automatically by the Thyratron tube coming into operation earlier or later in each cycle.

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(1) "A New Type of Stabilizer for Use with the Coolidge Tube," by W. K. Kearsley, *Jour. Radiology*, July, 1921.

(2) "Hot Cathode Thyratrons," by A. W. Hull, GENERAL ELECTRIC REVIEW, April and July, 1929.

Resistance *4* serves to increase the life of the filament by maintaining its temperature about normal while the high voltage is off. It also prevents overshooting of the tube current which would occur on applying the high voltage with the filament at a high temperature. Resistance *4* is made variable and is adjusted by the same handle that adjusts resistance *1;* so that whenever resistance *1* is set for some new value of tube current, resistance *4* is also set to give approximately the correct filament current for that value. When the switch *S* is closed, one blade short circuits the resistance *4* and the Thyratron tube immediately assumes control of the filament current.

It is evident, therefore, that this circuit does not maintain a constant filament current but, instead, makes the x-ray tube current itself the controlling factor to properly adjust the average filament current on each cycle so that the x-ray tube current is kept constant.

Use of Rectifier in Series with Transformer Primary As a Means of Reducing Inverse Voltage on Half-wave Load

By WILLIAM K. KEARSLEY
Research Laboratory, General Electric Company

WHEN a self-rectifying x-ray tube is operated directly from a transformer, the "inverse" voltage will be greater than the "useful" by an amount determined by the load, the design of the transformer, and the electrical characteristics of the supply circuit.

The useful voltage determines the x-ray production; but the inverse voltage, being the greater, is the one which the more severely taxes the insulation of both tube and transformer.

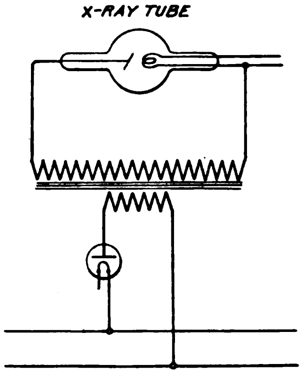

Fig. 1. Diagram of an X-ray Tube and Its Supply Transformer with a Rectifier in Series with the Primary Circuit

For a given circuit, the excess of the inverse over the useful voltage will increase with the milliamperage supplied to the tube. When the inverse becomes too great to be safely borne by the tube, a rectifying device can be employed in the secondary of the transformer but this will not furnish any relief to the transformer.

In those cases where it is desirable to keep the size and weight of the transformer to a minimum, as in oil-immersed x-ray apparatus for example, the problem of the inverse voltage becomes very important.

It has been found that a suitable rectifier placed in series with the primary of the transformer as in Fig. 1 will greatly reduce this inverse voltage, so that the allowable output from a given size of transformer is considerably increased.

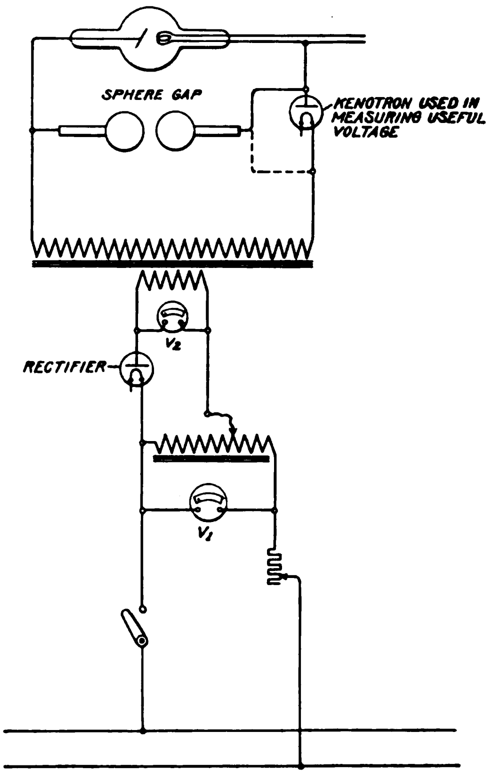

Fig. 2. Diagram of Connections and Measuring Instruments for Obtaining Electrical Data on the Combination of X-ray Tube, Transformer, and Rectifier

The figures in Table I were obtained from tests of a standard type of x-ray transformer.

It is evident that nearly three times the current can be drawn from this transformer with the rectifier in circuit as without it and still keep the difference between the useful and the inverse voltages the same.

To insure proper performance it is necessary so to connect the rectifier and x-ray tube that current flows in both on the same half-wave; *i.e.*, the anode of both should have the same sign at the same instant, otherwise the current drawn from the supply lines is excessive.

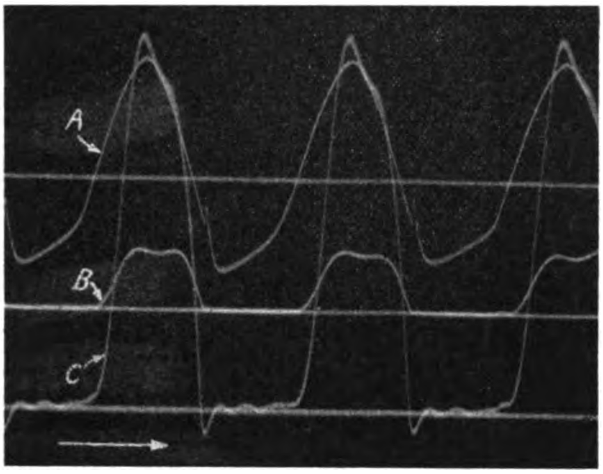

Fig. 3. Oscillogram of the Performance of an Oil-immersed X-ray Outfit with a Rectifier in Series with the Primary of the High-voltage Transformer

Curve *A:* Primary voltage, 240 volts
Curve *B:* Primary current, 50 amp.
Curve *C:* Secondary current, 80 ma.

This circuit is also very sensitive to small currents on the inverse half-wave. Even as small a current as one-half a milliampere drawn from the secondary on the inverse half-wave will produce a 200 or 300 per cent increase in the current drawn from the supply lines. This feature is a valuable one in that it shows when a tube fails to completely rectify the current, as occurs when the focal spot of the x-ray tube is overloaded.

TABLE I

WITHOUT RECTIFIER			WITH RECTIFIER		
Milli-amperes	Useful Voltage	Inverse Voltage	Milli-amperes	Useful Voltage	Inverse Voltage
30	85 kv.	92 kv.	30	85.5 kv.	87.5 kv.
			80	85 "	91 "
			90	85 "	100 "

Another valuable characteristic of this circuit is its behavior when connected to a supply transformer or mains which would otherwise be inadequate. The rectifier allows only the useful, or loaded, half-wave to pass but stops the unloaded half-wave which would normally be much higher in voltage. Table II shows the effect of line-voltage drop on the inverse voltage at the x-ray tube when the rectifier is used. The circuit employed, and the variable resistance connected in series with the supply to obtain these readings, are shown in Fig. 2.

TABLE II

LINE VOLTAGE		Voltage Drop	Load (ma.)	X-RAY TUBE VOLTAGE (KV.)	
No Load	With Loa			Useful	Inverse
213	200	13	0.80	85	91
213	182	31	0.80	84	92
214	154	60	0.80	85	105

The "no-load" and "with load" readings were taken on voltmeter V_1 before and after closing the switch. Therefore, the column marked "voltage drop" does not represent the full difference between the two conditions but it serves to illustrate the very large drop that can occur without appreciably changing the inverse voltage at the x-ray tube.

Fig. 3 shows oscillograph curves taken with the rectifier in circuit as in Fig. 1. The primary voltage, primary current, and secondary current are included. The primary-voltage vibrator was connected across the primary and shows not only the useful half-wave above the line but also the inverse voltage generated by the transformer during the half-wave when it receives no current from the line.

Multiple Winding Starting Method for Synchronous Motors

A New Method of Starting—Compared with Across-the-Line Starting, Compensator Starting, and Reactor Starting—Principle of Operation—Advantages and Limitations

By D. W. McLENEGAN and A. G. FERRISS
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"REACTOR starting characteristics without the reactor" are now made possible in the starting of polyphase synchronous motors by the use of multiple windings in the stator. Although full-voltage starting is now widely used for alternating-current motors of nearly all sizes, many cases still require starting controllers to reduce either the motor torque or the inrush current. While the auto-transformer (or self-contained compensator) has long been the general choice for such cases, the series reactor has come into use by virtue of its simpler switching arrangement and the smooth starting characteristics which it affords.

The multiple-winding method of starting involves an arrangement of the primary windings in such a manner as to increase the reactance and reduce the torque and kilovolt-ampere inrush. By making available this additional reactance in the motor windings during the starting period, it is possible to meet the requirements of many applications without an auto-transformer or an external reactor.

The development of multiple windings for motor starting follows from their use in large turbine-generators. By building such generators with independent windings, each of partial-load capacity, and connecting these windings to separate buses, the increased reactance has been used to limit the short-circuit current to values within the capacity of existing circuit breakers. A similar arrangement has been developed for synchronous motors to utilize part of the primary winding during starting and the complete winding for normal operation. In other words, the series reactor has been "built into the motor" for reducing the starting current.

The stator winding requires two (or possibly more) circuits with a special arrangement of stator coils that differs from the coil grouping used in the ordinary multiple-circuit windings. For the double-winding machine, if the two three-phase windings are designated as *A* and *B*, the coils of winding *A* will generally be laid in slots 1, 3, 5, 7, etc., and so on around the machine, while the coils of winding *B* will be laid out in slots 2, 4, 6, 8, etc., though other arrangements and variations may sometimes be employed. The connections and switching equipment will generally be arranged as in Fig. 1.

In starting, the three-pole running breaker will be closed, applying full voltage to the motor windings. The Y-point of one winding is permanently closed by a connection inside the machine, but the Y-connections of the second winding are brought out to a two-pole circuit breaker. This two-pole breaker is left open during starting, and therefore current flows only through one-half of the total number of stator coils. After the motor has reached a speed of 90 per cent or more, the two-pole breaker is closed by hand or by a relay. Current then flows through all of the stator coils, and the motor is ready to be synchronized by applying direct-current excitation to the field in the usual way. If the starting load is light, the motor may be synchronized before closing the Y-point of the second winding.

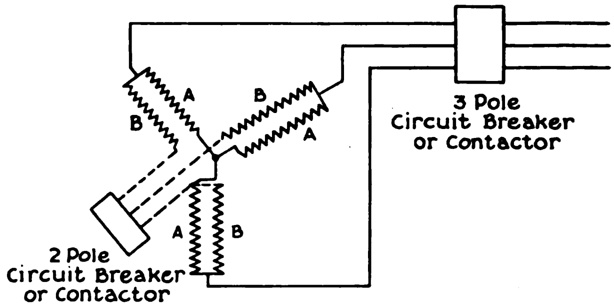


Fig. 1. Diagram Showing the Equipment and Connections for the Multiple-winding Starting Method

The starting characteristics obtained by this method are well illustrated by the tests taken on a synchronous motor rated 3000 hp., 125 r.p.m., 3 phase, 25 cycle, 6600 volts. This motor, which has been applied to drive a large gas compressor, has been built with a double winding and is started by the method shown in Fig. 1. Its torque-speed and current-speed curves are reproduced in Fig. 2, together with the characteristics which this motor would have if it were started at full voltage in the usual manner.

The starting torque is reduced to about one-half of the torque obtained with normal full-voltage starting and the starting kilovolt-amperes are about two-thirds of the locked rotor value. These percentages are fixed by the relative magnetic effects obtained with one circuit and with two circuits, and therefore are not capable of adjustment. However, as the motor comes up to speed, the torque does not remain at one-half of the normal full-voltage value; on the contrary, the effect obtained is similar to that of reactor starting.

As the motor accelerates, the torque tends to increase and to approach the full-voltage torque curve, so that when the second winding is energized at a speed of 90 or 95 per cent, there is only a small change in the torque developed by the motor. This "smooth starting" characteristic has always been the principal argument in favor of reactor starting. After power has once been applied to the motor, the circuit is never interrupted.

Motor efficiency is generally unchanged or may be very slightly reduced by the use of double windings, providing their use is limited to a suitable range of motor ratings. For very small motors at high voltage, such as those of 50 hp., 2200 volts, the double winding is not desirable. Since a single-circuit Y-connection is the usual arrangement in such cases, the introduction of a double winding, or a two-circuit connection, would necessitate twice the total number of turns in the winding. With the same total space available for copper, the cross-section of the individual conductors would necessarily be reduced, and the use of extremely small conductors is undesirable in the manufacture of motor coils.

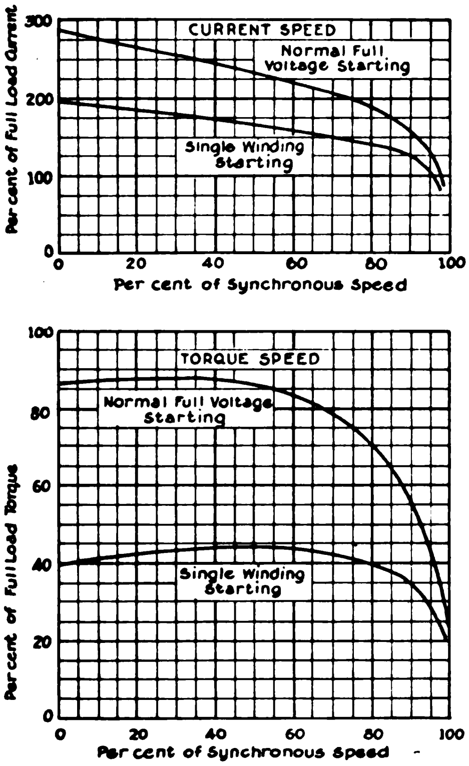


Fig. 2. Comparison of the Current-speed Curves and the Torque-speed Curves When Starting a 3000-hp. 125-r.p.m. 25-cycle 6600-volt Synchronous Motor by the Normal Full-voltage Method and by the Method Employing but One Circuit of a Multiple Winding

Conversely, the double-winding may encounter limitations in very large motors of low voltage, since it becomes difficult to make the necessary connections between coils with very heavy copper. Fortunately, plant distribution costs usually eliminate these extreme cases and result in the use of voltages which allow the motor designer some latitude in the arrangement of windings. Hence there will be relatively few cases in which the double winding must be ruled out because of winding difficulties.

In general, this method of starting may be used for starting any load which could be started by the same motor with an auto-transformer connected through a 70 per cent tap. It is always possible to close-in the second winding, if necessary, before synchronizing, to obtain the normal pull-in torque.

For some applications where the starting duty is relatively light, it is sometimes necessary to limit the starting current to much less than two-thirds of the locked-rotor full-voltage value, and in these cases the simple double-winding starter is not applicable. For example, synchronous motor-generator sets of which the motor starting current at full voltage may be as high as six times normal may be required to start without exceeding the full-load current from the line. Such a requirement would necessitate the use of an auto-transformer with low-percentage taps, or a series reactor designed to give a much greater reduction in starting current than would be possible with the double-winding starter. For such cases it is possible to use double windings connected in series for starting and in parallel for running; but this arrangement results in a complicated switching equipment. However, double-winding starting is well adapted to the drive of such loads as fans and pumps, in which the load increases with the speed. Fig. 3 shows the torque-speed curve of a centrifugal pump starting with the discharge valve closed and, for comparison, typical torque-speed

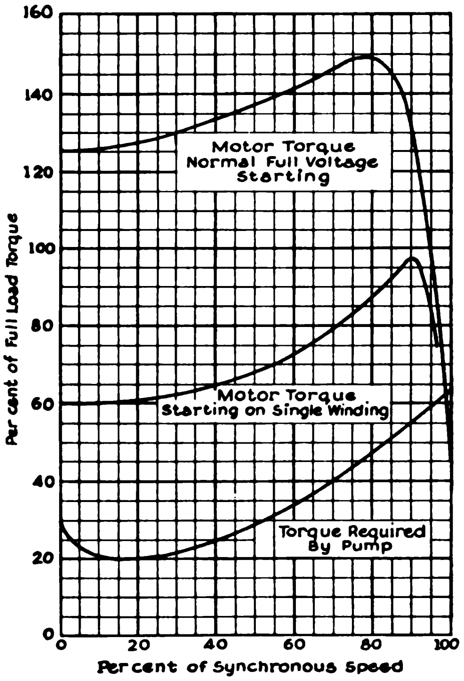


Fig. 3. Torque-speed Curves of a Centrifugal Pump and of Its Direct-connected Synchronous Motor When Started by the Normal Full-voltage Method and by the Method Utilizing but One Circuit of a Multiple Winding

curves of a general-purpose synchronous motor with normal starting on full voltage and also with the double-winding starting method. It has been suggested for starting certain large motors such as pulp grinder motors, in which the starting duty is relatively light.

In some applications requiring high starting and accelerating torque, it may be undesirable to throw the motors across the line because of the strains which would result in gears, belts, or other mechanical parts. The double-winding starter offers a convenient way out of this difficulty. With the first winding energized, the motor will deliver a reduced torque. This may not be enough to start the machine, but it will "take up the slack" in the belting or gearing. The closing of the second circuit, after one or two seconds, will enable the motor to develop its full torque without throwing any shock on the mechanical transmission. This is one of the most important possibilities of the double winding, and it promises to be particularly useful in geared or flexibly connected drives.

Certain applications arise where the motor has inherently a higher starting torque than needed—notably the low-speed 25-cycle synchronous motor for reciprocating compressor drive. This high torque is sometimes objectionable to the compressor builder. The double-winding starter offers a simple way of reducing the torque to an acceptable value and allows also a material reduction in starting current.

Undoubtedly, a great many more applications for this type of starter will be found and it should have a wide field of use.

As compared with primary-reactor starting, the double-winding starter saves the floor space which the reactor would require. As compared with auto-transformer starting, it saves not only floor space but also one switch or breaker, since an auto-transformer starter requires the combination of a three-pole and a five-pole switch, or three separate switches. If the equipment is designed to interrupt a heavy short-circuit current, the double-winding starter possesses an additional advantage. The severe interrupting duty will be confined to the running breaker. The second breaker may be of relatively small capacity since it is protected by the impedance of the motor windings.

The reduced current inrush results from the increased reactive effect due to localizing the winding in half the total number of slots completely around the machine, thus reducing the reluctance of the slot leakage flux paths. That is, the reactance of the motor when started across the line, with only half of the coils energized in alternate slots, is much greater than the reactance of the same motor with all of the coils energized and has the same effect as a series primary reactor. Because the reduced input does not create as high a flux to act on the amortisseur winding as the full current would, the starting torque is consequently reduced.

The double-winding idea has been extended to a three-winding arrangement. The Y-point of one winding is permanently closed inside the machine. The Y-points of the second and third windings are closed by two two-pole switches as the motor comes up to speed.

Calculations indicate that the three-winding method will show very little advantage over the two-winding method as a means of reducing current inrush, since the increased reactive effect due to localizing the windings in every third slot will not be appreciably greater than localizing the double windings in alternate slots. Also there may be low points in the torque curve, which may cause the motor to hang at part speed. This might be overcome by closing the neutral of one phase completely and leaving the two-pole breakers to operate on the remaining Y-points of the second and third phases, or by a different arrangement of connections. Such modifications however would reduce the reactive effect, giving less reduction in the current inrush.

The range of application of the three-winding method appears to be very limited and although the use of three windings may occasionally be advisable for increment starting, it is believed that the added complication will not often be justified.

The multiple-winding starting method is also applicable to polyphase induction motors, although at present each design must be carefully considered to insure successful operation. With the smaller air gap of the average induction motor, appreciable harmonic torques may result when starting with alternate coils energized; and these harmonic torques, in combination with the fundamental torque, may cause low points in the torque-speed characteristic. However, the occurrence of this condition can be detected in advance by an analysis of the motor design. Therefore, by making proper provision to minimize the harmonic torques, multiple-winding starting may be successfully applied to induction motors as well as to synchronous motors.

Switchgear at the 250,000-kw. Steam Generating Plant at Stalingrad, U.S.S.R.

By ALEX. J. COWAN
Switchgear Department, Philadelphia Works, General Electric Company

THE five-year program of industrial expansion of the government of the United Socialist Soviet Republic includes increasing the output of electric generation from 5,160,000,000 kw-hr. in 1928 to 22,000,000,000 kw-hr. in 1933. Engineers of Soviet Russia in their determination to succeed have planned the immediate development of the more important and larger power sites. These are located strategically with respect to factories which require power.

One of these developments is on the Volga River at Stalingrad. The power station, now in course of construction, will have steam turbine-generator capacity of 60,000 kv-a. with provision for increase in the near future to 170,000 kv-a. and ultimately to 250,000 kv-a. Power will be generated at 11,000 volts, 50 cycles by two generators and stepped up by their individual transformers to 115,000 volts for transmission some 130 miles to factories and municipalities. The more important of these factories are steel mills and woodworking mills, and the most important is a tractor factory. This tractor factory is entirely new and is expected to be ready for operation near the end of this year; the power station, therefore, must keep pace.

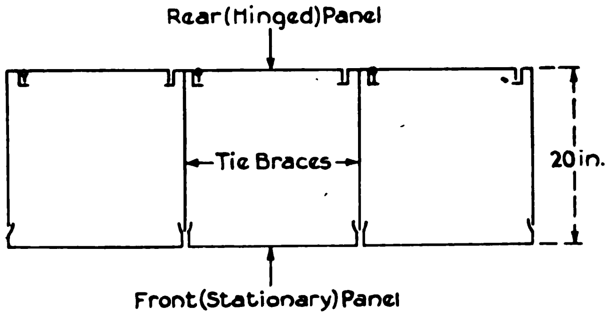


Fig. 1. Plan View of Duplex-unit Metal Switchboard Construction

Each generator will be connected to 11,000-volt bus bars for paralleling and for furnishing power for station auxiliaries and some local distribution. Service transformers will reduce the voltage to 3300 volts, three-phase for supply to double station-service buses. To one of these will be connected essential auxiliaries and to the other, non-essential auxiliaries.

A unique feature will be employed to maintain an adequate supply to the "essential" bus. This will be an over-excited auxiliary generator which will normally float on this bus as a synchronous condenser. Upon failure of supply through the service transformer, or a 25 per cent drop in bus voltage, the "essential" and "non-essential" buses will be separated and the generator governor and automatic voltage regulator will act to place it in service and assume the load.

The switchgear, including primary equipment and secondary control with the control and indicating boards, will represent the latest design in details and in assembled product for central-station switching.

The control boards will be entirely of steel with welded steel frameworks. The main circuits will be controlled from a "bench" type of control and indicating board.

On the front of this board (in a convenient arrangement of control switches, potential and synchronizing switches, and indicating instruments) will be the control for generators, transformers, transmission lines, and 11,000-volt station transformer and local distribution. The back panels will accommodate watthour meters, reactive volt-ampere-hour meters, totalizing recording wattmeter for generators, and the necessary relays.

The 3300-volt service generators, transformers, and motor circuits in the generator station and also all circuits in the receiving stations will be controlled from 90-in. high vertical duplex-unit switchboards.

The material is entirely of steel with the control and indicating instruments on the front and with the watthour meters and relays on the hinged rear panels.

These hinged rear panels will be located just 20 in. back of the front panels. Access to small wiring and devices on any particular circuit will be through this door. This type of steel board requires a minimum of floor space and greatly facilitates shipment and installation.

For generator relays and regulators, a steel swinging-type wall panel will be used. This panel design is compact and is intended for mounting close to the wall. The back-of-panel space will be accessible when in the open position. The wall space back of the panels will offer a convenient place for mounting conduits, fuses, and terminal boards. Flexible-cable connections will be used for interconnections between wall and panels. The cable will be firmly clamped to the panel and the wall, thus eliminating the strain from the terminal blocks.

All watthour meters and reactive volt-ampere-hour meters and relays will be equipped with testing and calibrating devices which will permit any form of testing. The same devices will also be used in calibrating the indicating instruments.

The control boards will be completely factory built and so shipped in units, or in groups, as their size

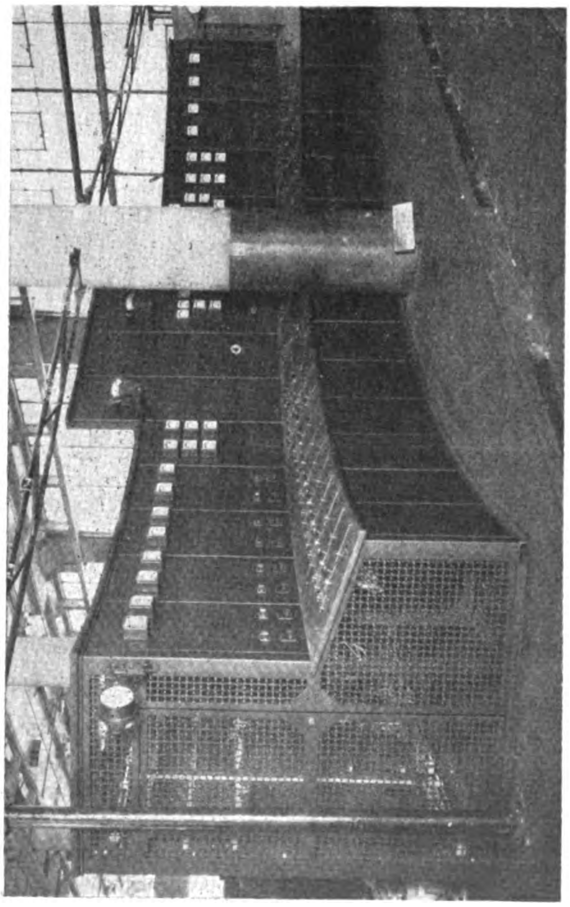


Fig. 2. Front View of the Main Control Benchboard During Assembly in the Factory

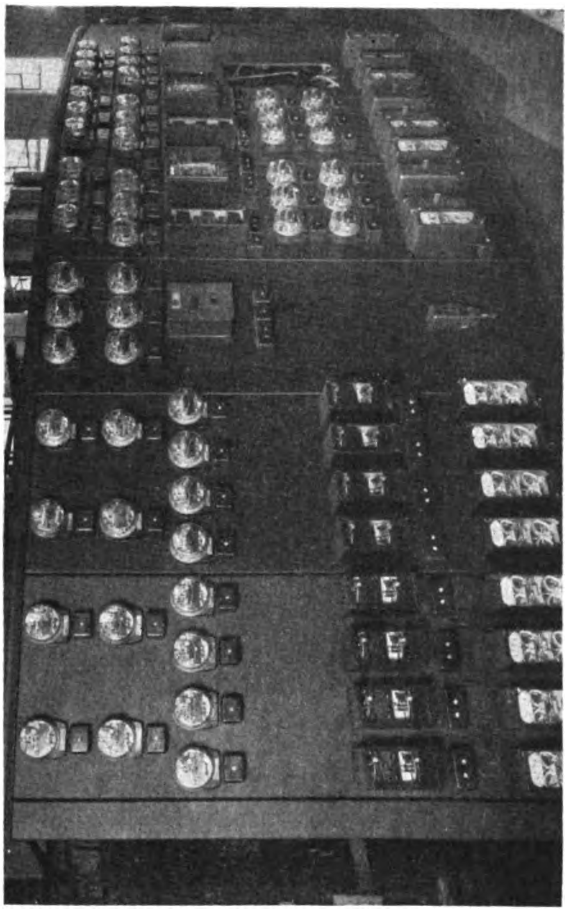


Fig. 3. Rear View of the Main Control Board During Assembly. On this side are mounted relays, and integrating and recording meters

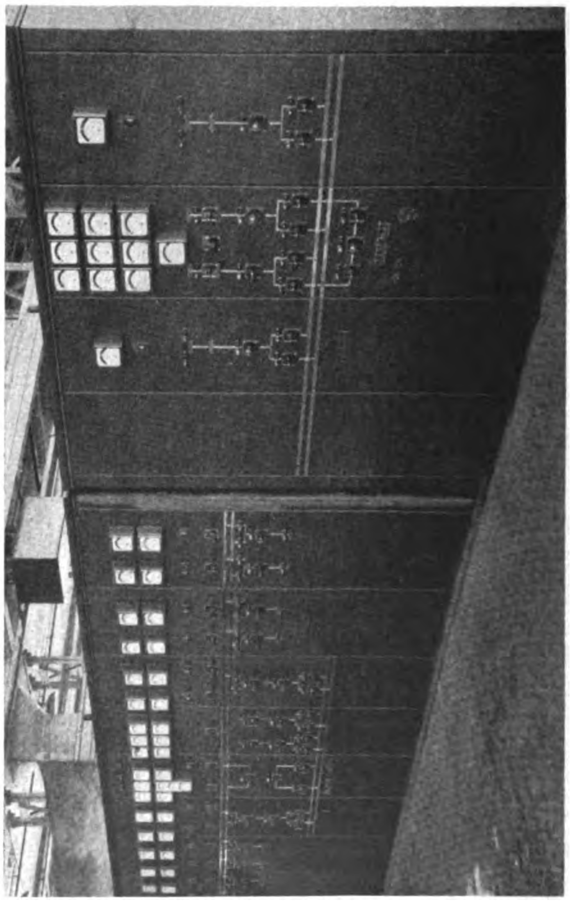


Fig. 4. Front View of Duplex-unit Metal Switchboard

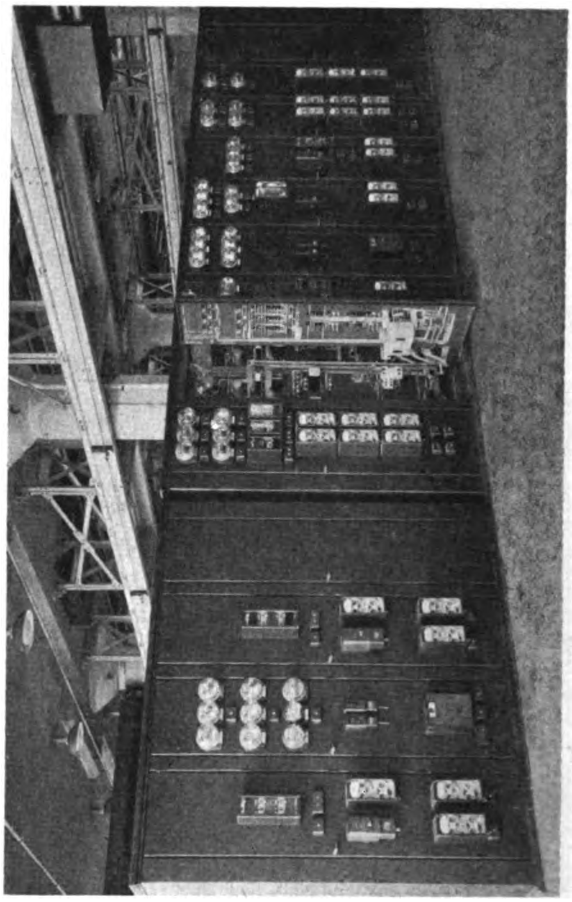


Fig. 5. Duplex-unit Metal Switchboard, Showing Hinged Rear Panels

permits. The front and back panels with framework will mount all equipment including the secondary wiring, auxiliary relays, fuses, etc. The small wiring will be brought to terminal blocks near the bottom of the panels with provision for marking the leads and groups of leads, corresponding to the wire numbers and cable letters shown on the diagram of connections.

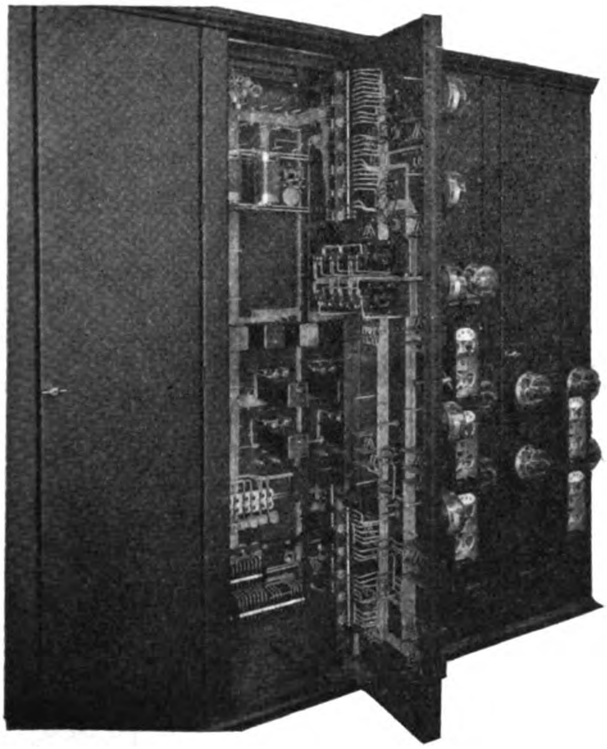


Fig. 6. Vertical-type Duplex-unit Instrument and Control Switchboard with Hinged Rear Panels, Showing Secondary Wiring

The power generated will be totalized in a recording kilowatt meter. Indication of this total kilowatts will be transmitted to indicators; *viz.*, one 24-in. dial indicator on the front of the main control benchboard and another in the chief engineer's office, also one 36-in. dial indicator in the turbine hall and another in the boiler room. This remote indication will be accomplished by the use of a Selsyn generator and motors located in the totalizing recorder and indicating instruments. These small Selsyn motors change their

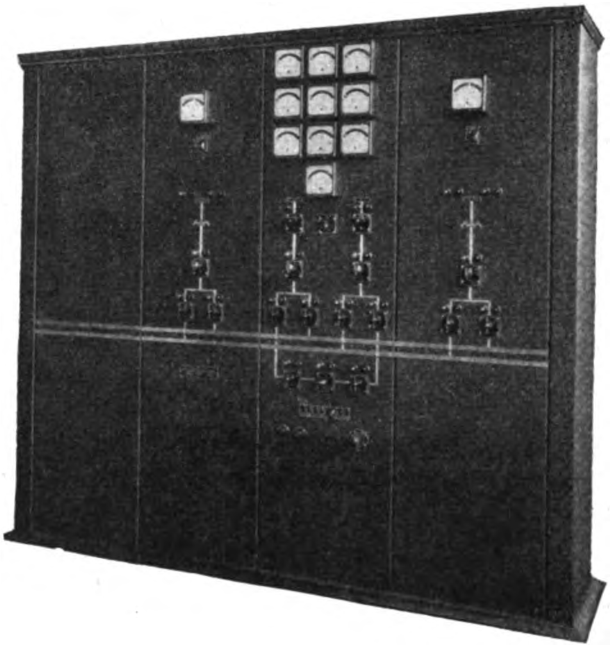


Fig. 7. Control Panels for High-tension Incoming Lines and Transformers in Tractorstroy Substation

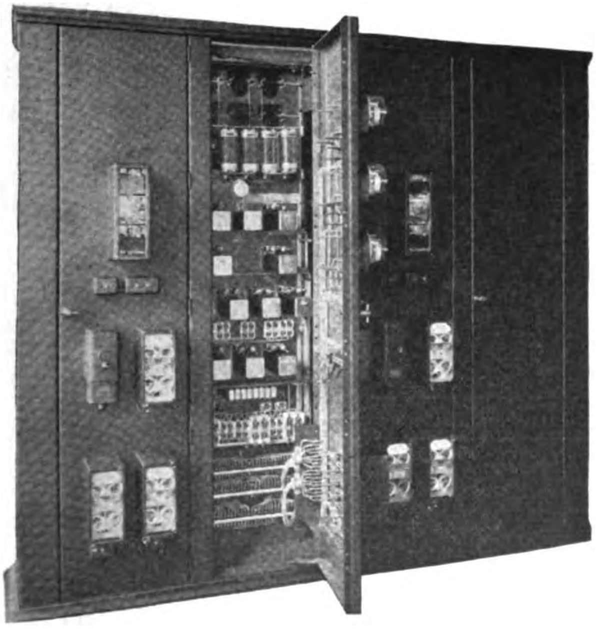


Fig. 8. Hinged Rear Relay Panels for High-tension Incoming Line and Transformer Control Board, Tractorstroy Substation

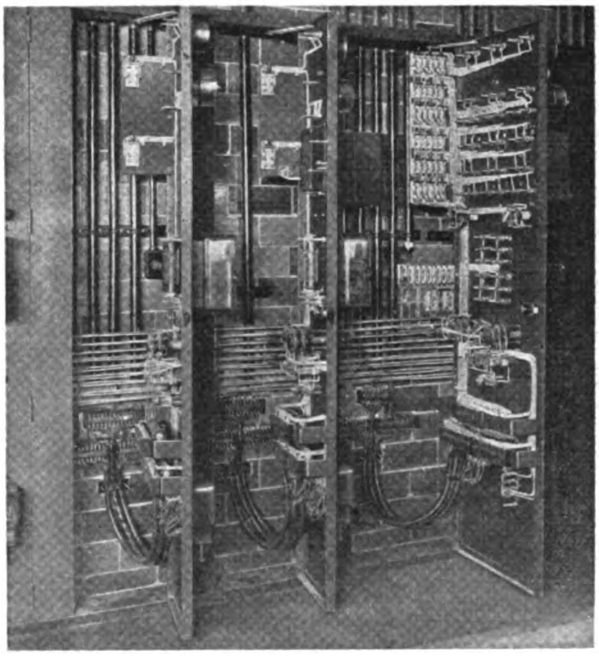


Fig. 9. Steel Hinged-type Wall Panels for Generator Relays and Regulators

position exactly corresponding to the change in rotor position of the Selsyn generator in the recorder.

In the same manner, using Selsyn equipment, the anticipated change in load demand will be transmitted from the control benchboard to the turbine hall and boiler room.

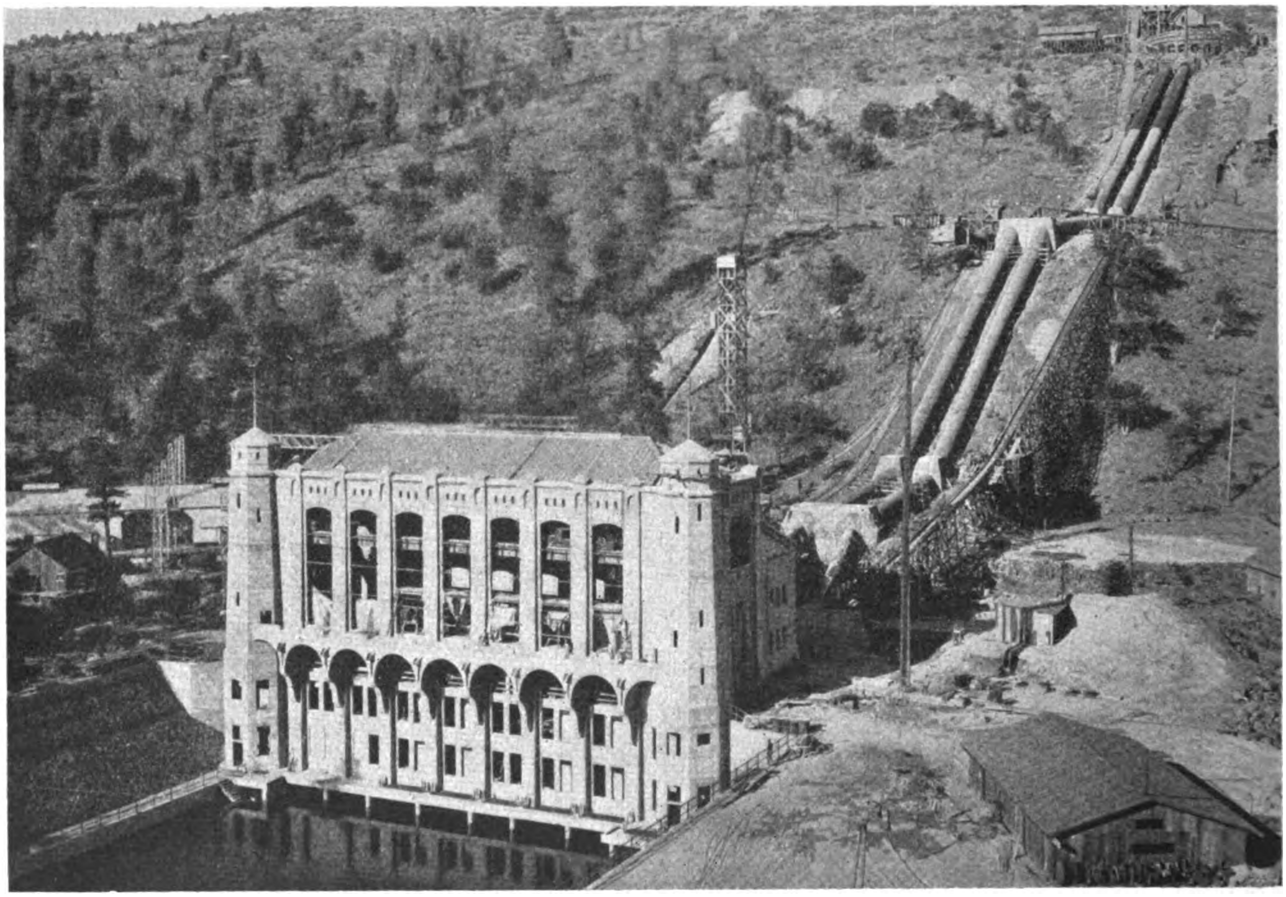
The use of Selsyn devices will again be employed for signalling required operations from the operating room to the attendant on the turbine floor.

In the high-voltage circuits, electrical interlocking will be used between the oil circuit breakers and the disconnecting switches. The oil breakers must be in the open position in order to operate the electrically-operated disconnecting switches. An exception to this interlocking will be in connection with the high-voltage bus selector disconnecting switches, in that their interlock with their oil circuit breaker will be unlocked, upon the closing of the bus tie disconnecting switches and oil circuit breaker, thus permitting the transfer of a circuit from one bus to the other without interruption of service.

The line disconnecting switches will be equipped with grounding blades manually operated and interlocked with the motor-operated main switch, for the purpose of grounding the line whenever workmen are engaged in construction work.

Synchronizing will be accomplished, between the generators and either 11,000-volt bus and around all high-tension oil circuit breakers, by the use of the conventional potential transformers on the low-voltage side and bushing potential devices in the bushings of the breakers on the high-tension side.

A California Power House



A Power House of the Pacific Gas and Electric Company on the Pit River

Classification and Physical Tests for Various Types of Welded Plate Joints

Variables Affecting Classification—Comparison of Rolled Steel and Deposited Steel—Effects of Ductile Extensibility—Test Specimens—Test Results—Comparison of Characteristics

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IN the study of weld-fabricated joints, it should be borne in mind that the base and weld metals are strained simultaneously and rupture may occur in either, depending entirely upon the composite qualities of the physical properties of the specimen as a whole. The results obtained from "slow" or "equivalent static" tensile tests for a series of similar specimens are comparable when the assembled parts of the unwelded specimens conform to a definite size, shape, and gauge length. The extra material required to make the joint is disregarded in this respect.

The physical properties or "variables" can be measured by the degree of fluctuation from those found for a plain unwelded specimen of the base metal, tested under the same conditions. Fabricated specimens are not suitable for obtaining individual properties of either the weld or base metal. When such results are desired the specimen should be made entirely of the metal under consideration.

When the specimen is built-up for any given case it may be regarded as a working specimen, and a general classification of the results should be made with due regard to the limitations of the conditions under which the test was made. Any variation in the quality, size, or disposition of any one of the different elements will greatly influence the results for the others.

It is generally known that direct stresses are more evenly distributed and transmitted by members having uniform symmetrical sections than by those with abrupt or unsymmetrical changes. It is easily understood that unsymmetrical changes in section will induce complex moment stresses in addition to the direct stress; and an abrupt change will complicate the flow of the metal, there being a restriction at the greater mass, while the work of rupture will be confined to the minimum section, and high local stresses will develop at sharp corners and reëntrant angles, the effect of which will be felt most in a brittle or non-extensible metal.

From the preceding remarks it is not difficult to define the variables upon which a classification of the various types of welded joints can be based. Briefly stated, these are as follows:

(*a*). A uniform section.
(*b*). An abrupt symmetrical change in section.
(*c*). An abrupt eccentric change in section.
(*d*). Like metals.
(*e*). Unlike metals.

The term "like metals" refers to an ideal duplication in the weld metal of all the strength properties, elastic constants, and ductility possessed by the base metal. To produce a weld metal essentially the same as the base metal would require full control of the metallurgical, chemical, and technological processes applicable to the "variables" involved, namely:

(*f*). Ultimate strength.
(*g*). Elastic limit.
(*h*). Yield point.
(*i*). Energy of rupture.
(*j*). Ductility.
(*k*). Endurance limit.
(*l*). Direct modulus of elasticity.
(*m*). Transverse modulus of elasticity.
(*n*). Physical structure.

The stress-resisting qualities of these properties may be stated as:

(*o*). Strength.
(*p*). Resilience.
(*q*). Adaptability to overstrain.
(*r*). Impact resistance.
(*s*). Fatigue resistance.
(*t*). Volumetric elastic deformation.
(*u*). Effective stress distribution.

Disregarding the unlimited range of these variables for all kinds and grades of metals, this article will be confined to mild steel and a suitable grade of welding wire. The properties to be found in a deposit of mild steel weld metal as compared with those for a similar grade of rolled steel may be stated as follows:

(*v*). The ultimate strength, elastic limit, direct and transverse modulus of elasticity are quite normal.

(*w*). Tests for ductility and elongation indicate irregularities in these properties.

(*x*). In regard to the endurance limit as a measure of fatigue resistance, the information at hand does not warrant a statement at this time.

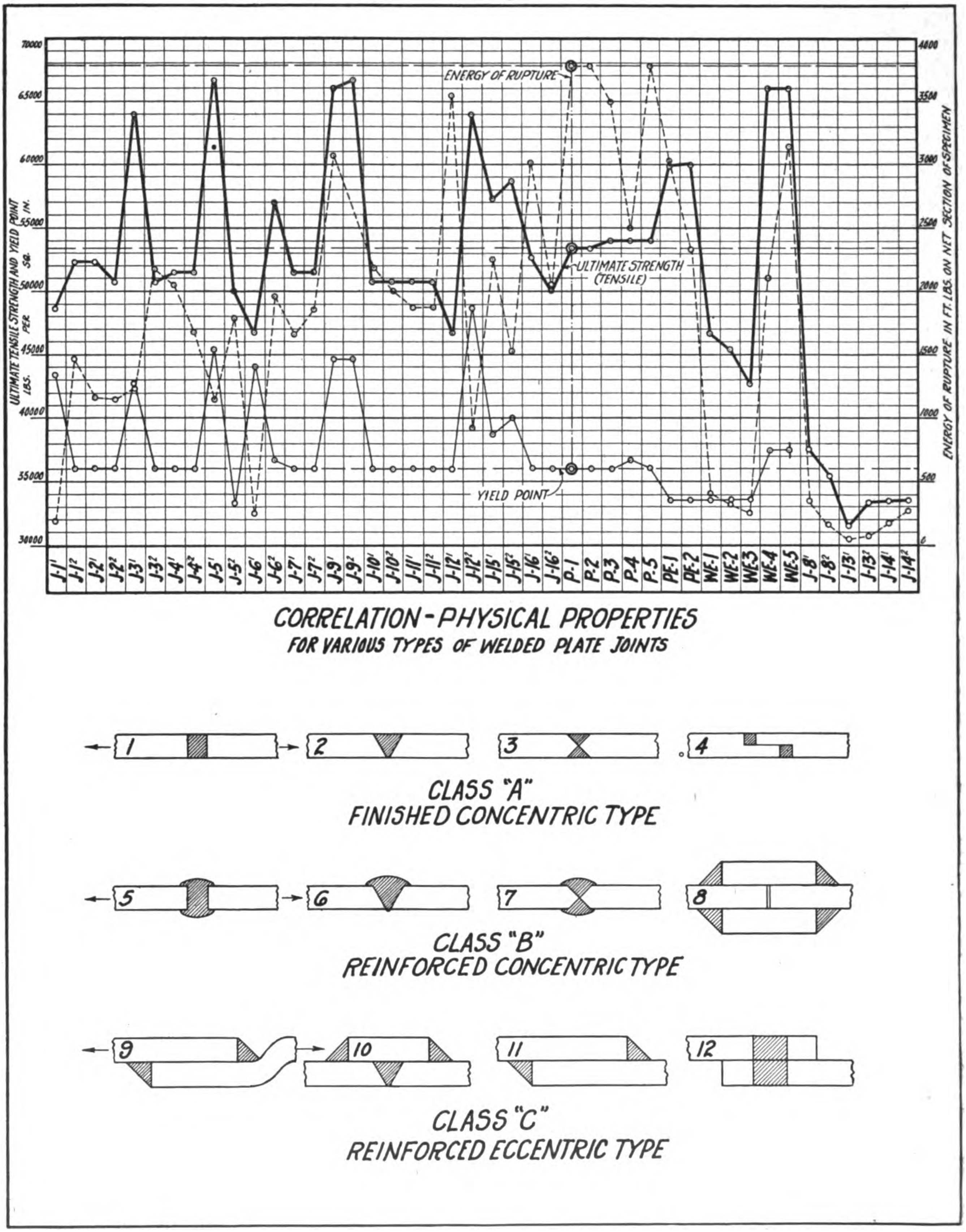

Fig. 1. Physical Properties of Various Welded Joints

Joints *J-1* to *J-6* embody an abrupt eccentric change in section.
Joints *J-7* to *J-12* embody an abrupt symmetrical change in section.
Joints *J-13* to *J-16* are special types of joints

Specimens *P-1* to *P-5* are plain plate sections.
Specimens *PE-1* and *PE-2* are plain plate sections of special eccentric type.
Specimens *WE-1* to *WE-5* are welded joints of special eccentric type.

(*y*). The physical structure of weld metal is a much discussed topic and rightly deserves such consideration, as this is probably the most erratic variable of the entire group. Structural investigations should include all physical irregularities such as flaws, shape, and inclusions as well as the natural crystalline formation. Structural faults are usually referred to as contributions from poor equipment, bad manipulation, inferior materials, lack of supervision, incorrect designs, inexperienced welders, and even the disposition and personality of the welder.

Aside from what has been said, good weld structures can be, and are being produced on a large scale by both hand and automatic processes, and whatever difficulties exist from these sources will eventually be corrected by proper materials, equipment, supervision, inspection, and process procedure control.

Referring to the classification variables (*a*), (*b*), (*c*), (*d*), and (*e*) for various types of joints it is easily seen that a uniform section (*a*) and like metals (*d*) would produce a perfect joint, although a uniform section and unlike metals would be inefficient as regards the affected variables of the weld metal. An abrupt symmetrical change in section (*b*) and like metals (*d*) would be inefficient as regards volumetric elastic deformation essential to proper stress distribution.

With an abrupt eccentric change in section (*c*) the conditions for the previous case would exist with further complications from complex moment stresses due to the eccentricity.

The next point for consideration is a practical one, and may be regarded as a logical compromise between theoretical and practical deductions. Theoretically, the perfect joint would consist of like metals and a uniform section, *i.e.*, the weld would have to be finished flush with the plate surfaces. A practical joint for economical reasons would be as deposited, unfinished, and would extend outside the plate surfaces, to insure a full thickness of joint. The weld metal as regards some of the variables would be unlike the base metal. Here it will be well to mention the lack of ductile extensibility, and the structural irregularities of ordinary weld metal which primarily possesses the characteristics of cast metal.

Ductile extensibility has to do with the energy of rupture, a measure of resistance to impact and adaptability to overstrain, the latter being associated mostly with the incidental bending stresses induced by eccentric connections, scant welds, or accidental irregularities such as flaws or inclusions in the weld structure.

Taking into account the irregularities mentioned it is to be observed that the naturally deposited or unfinished weld, when made symmetrical and somewhat thicker than the plates joined, affords a means of reinforcement against failure in this manner. The practical joint would therefore consist of the variables (*b*) and (*c*), an abrupt symmetrical change in section, and unlike metals.

The effect of this type of joint is to increase the resistance to lateral contraction parallel to the joint. The weld metal acting as a strut or stiffener will be subject to the stress considerations for such members. The plates adjacent to the weld will receive an unequal distribution of stress with subsequent abnormal effects.

Aside from considerations of strength, the added weld metal of a reinforced weld will provide against porous leaks, an essential factor in pressure vessel construction.

For purposes of identification, the classification variables (*a*), (*b*), and (*c*) are shown in the lower section of Fig. 1, respectively, as classes "*A*," "*B*," and "*C*." Other classifications may be made with the metal variables (*d*), and (*e*).

Specimens

The type of specimen selected for this work is not an all-purpose type, but rather a very specific one. The gauge length and width conform to the A.S.T.M. standard for plates and flats. This specimen should not be confused with the ordinary type generally used for shear tests on fillet welds. The stress-strain curves obtained with this specimen are of particular advantage as a measure of ductility.

Reference Symbols

The markings for the various specimens are as follows:

J—Indicates a welded joint.
P—Indicates a plain plate.
PE—Indicates a plain plate—special eccentric type.
WE—Indicates a welded joint—special eccentric type.

The *J* specimens were made in pairs, the individual specimens being indicated by the small numeral exponents (1 and 2) written with the joint number given under the photographic reproductions of each of the specimens.

Material

The material used for all *J* and *P* specimens was an ordinary grade of tank plate. The physical properties are shown by Curve *P-1* in Fig 2 and are given for comparison in several cases as indicated by the dotted lines superimposed on the curves of the various joints. Specimens *PE* and *WE* were made from structural steel flats. All specimens were ¼ in. thick except *J-8*, which was ¾ in. An ordinary grade of welding wire was used in all cases.

Diagrams and Photographs

The stress-strain curves are shown in Fig. 2. The vertical or stress scale gives the *actual load* on the net section of the specimen. The horizontal or strain scale

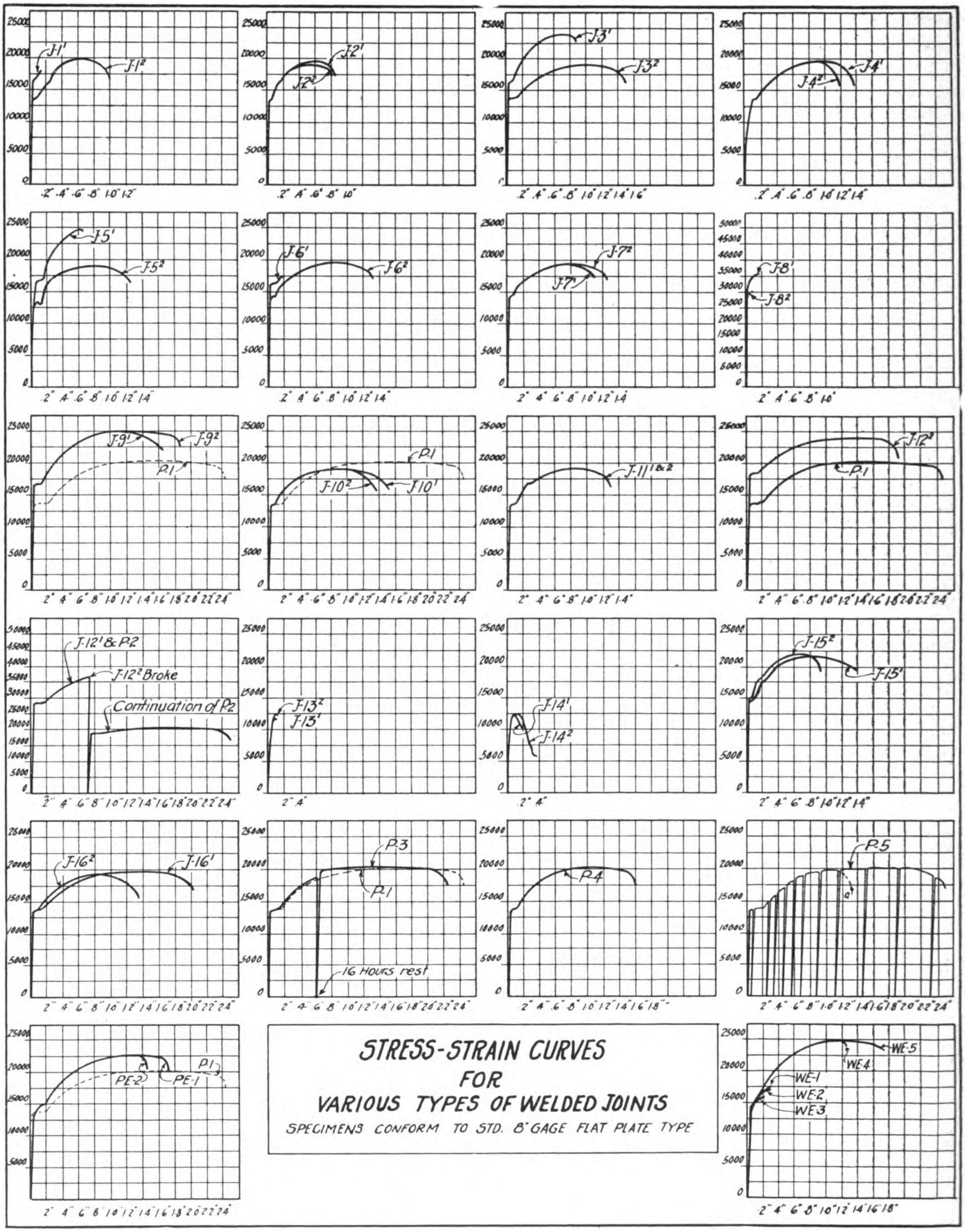

Fig. 2. Stress-strain Curves for Various Welded Joints

Joints *J-1* to *J-6* embody an abrupt eccentric change in section.
Joints *J-7* to *J-12* embody an abrupt symmetrical change in section.
Joints *J-13* to *J-16* are special types of joints.
Specimens *P-1* to *P-5* are plain plate sections.
Specimens *PE-1* and *PE-2* are plain plate sections of special eccentric type.
Specimens *WE-1* to *WE-5* are welded joints of special eccentric type.

is in inches. Fig. 1 shows the correlation of all the calculated properties. In Figs. 3 to 8 inclusive the specimens have been arranged in pairs, one on each side of the line sketch of the joint. Two views of specimens *J-1* to *J-12* inclusive are shown. For the others only one view is given. The markers at the edge of the specimens indicate the elongation.

General Remarks

In addition to the accompanying diagrams and photographic reproductions of all the specimens, observations were noted during test and a careful post-examination made of each specimen. The information was then tabulated and examined for fundamental data. It was first intended to report these data as collected for each of the specimens. On second consideration, and in view of the recurrence of similar results, it appeared that a more comprehensive understanding would be had from a general treatment with proper reference to specific cases. The results are therefore reported in the following general summary.

SUMMARY OF TENSILE TEST RESULTS

Variable (*a*): A Uniform Section

Two specimens of this type (*J-12* and *J-16*) were tested. Specimen *J-12*^{1} was machined slightly below the surface of the plates to insure rupture in the weld. The test was made in parallel with a plain specimen *P-2* inserted at the same time for comparison. With only a few thousandths of an inch reduction in section, rupture occurred at a little over 0.7 in. elongation. Specimen *J-12*^{2} was machined a comparative amount oversize, resulting in about 1.8 in. elongation. The slight difference in size was sufficient to transfer the concentrated energy of rupture from the weld to the adjacent plate.

Specimen *J-16*^{1} was finished exactly flush with the plate surfaces. The results obtained for this specimen were more nearly normal compared with a plain plate than for any other type tested. The results in terms of efficiency as compared with *P-1* are given below:

Ultimate strength	99 per cent
Yield point	100 per cent
Energy of rupture	81 per cent

From these results it would seem that good evidence of the effects of the variable (*a*) is to be found in this specimen. Specimen *J-16*^{2} was not finished exactly flush with the plates, the welds being slightly reinforced. The result was a lower energy of rupture.

Variable (*b*): An Abrupt Symmetrical Change in Section

Five specimens of this type (*J-7*, *-8*, *-9*, *-10*, and *-11*) were tested. All broke in the plates except *J-8*, which was intended to break at the welds, the plate in this case being ¾ in. thick. (Specimen *J-10* has the appearance of an unsymmetrical section. A number of tests with this type of specimen warrant the classification it has been given here when proper reinforcement and good penetration are assured.) The fact that all of the ¼-in. specimens broke in the plates would seem to be evidence of the reliability secured by the equal stress distribution in the welds when the section is symmetrical. The absence of bending is also apparent in the straightness of the specimens after rupture.

Referring to specimens *J-7*, *-10*, and *-11* (Figs. 5 and 6), it will be seen that elongation was restricted to the ruptured plate while both sides of *J-9* were elongated. This shows a better distribution of stress and accounts for the greater energy of rupture for this pair of specimens, which are obviously the outstanding members in this class.

Specimens *J-7* and *J-8* were made for comparison. The straps and welds were made alike; but *J-7*, made from ¼-in. plate, was intended to break in the plate. Specimen *J-8* was ¾ in. thick and intended to fail in the welds. The purpose was to determine the factors for both conditions. The ultimate strength of the plate was found to be 51,400 lb. per sq. in. The welds were good for an average of 34,000 lb. per joint. The thickness of plate that could be developed by the welds would be 0.66 in. The ultimate strength of a plain specimen (*P-1*) was 53,400 lb. per sq. in. Using this as a basis, the ultimate strength efficiency would be 96 per cent. From similar reasoning the energy of rupture would be reduced to 47 per cent. These differences may be regarded as the effects of an abrupt symmetrical change in section.

Variable (c): An Abrupt Eccentric Change in Section

Nine types of this class (*J-1*, *-2*, *-3*, *-4*, *-5*, *-6*, *-13*, *-14*, and *-15*) were tested, making eighteen specimens in all. Nine of the eighteen broke in the welds. There is no doubt that bending was not the chief contributor to these failures. An examination of the photographs (Figs. 3, 4, and 7) will bear out this statement.

Out of the nine pairs tested, the failures of five alternated from weld to plate. That is, one occurred in the weld and one in the plate for each pair. This is probably due to the excessive bending stresses present in this type of joint, and would seem to indicate that the margin of resistance in either case is rather small. An examination of the weld fractures gave further evidence of the slight variation in the weld structure required to cause failure in this manner. Referring to *J-1*^{1}, as an example, the fractured weld showed an eight per cent reinforcement on the strap side of the "V" weld and a five per cent lack of penetration for the opposite side. With this scant reinforcement and the breach at the extreme tension fibers the conditions were favorable for a rapid failure. As indicated in the stress-strain diagram, failure occurred within an elongation of about 0.2 in., giving a very low energy of rupture. An examination of *J-1*^{2}, which failed in the plate, showed 20 per cent reinforcement with only two per cent lack of penetration, which was sufficient to transfer most of the bending to the adjacent plates as indicated by the bends at these points.

Specimen *J-3*^{1} gave a similar result to that for *J-1*^{1}. In this case failure was due to an inclusion (at left-hand side of fracture shown in Fig. 3) which again gives evidence of the small margin of safety in resisting the excessive bending stresses in this type of specimen.

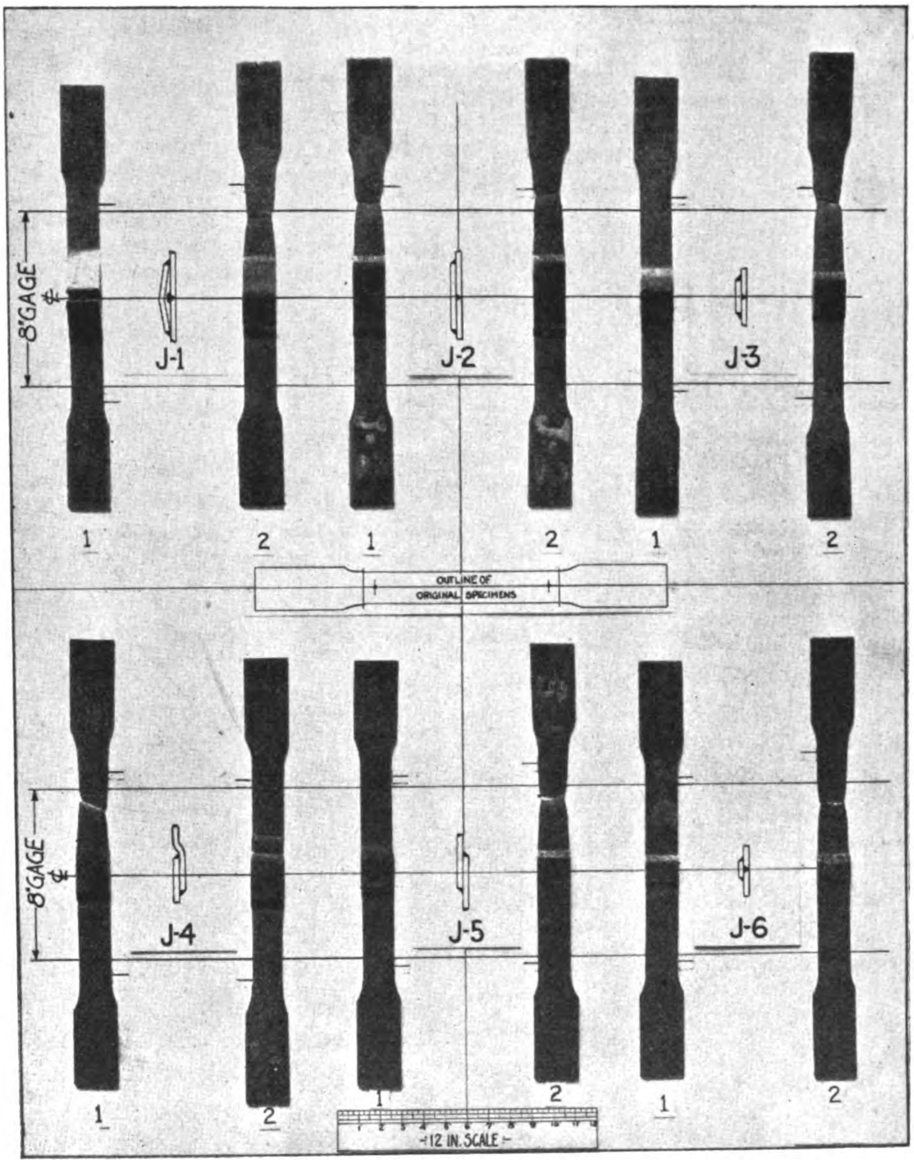

Fig. 3. Joints Having an Abrupt Eccentric Change in Section (Front View)

As a check on the variable (*c*), specimen *P-4* was made for comparison with *J-3*^{2}. The same size strap was welded to a plain specimen to observe the effects of the abrupt eccentric change in section due entirely to the added metal. The following are the comparative results based on those for *P-1*:

	J-3^2	*P-4*
Ultimate strength...	95 per cent	100 per cent
Yield point.........	100 per cent	100 per cent
Energy of rupture...	57 per cent	66 per cent

The results are practically the same, showing the major loss as compared with *P-1* to be in the energy of rupture. Considerable bending was also in evidence.

TESTS OF DUCTILE ADAPTABILITY TO OVERSTRAIN

In a great many cases the ultimate failure of a joint is initiated by incidental bending stresses. These stresses are due to some form of eccentricity existing in the connection. Although plastic as well as ductile deformations are involved in bending, it is the extreme tension fibers which are affected most. When an eccentric member has sufficient ductile resistivity to endure the incidental bending induced by an axial adjustment to direct stress, some of the fibers may have been dangerously overstrained. Any additional overstraining would result in a complete failure by rupture, should the adjustment have alleviated all conditions for additional overstraining by permanent deformation and a small margin (say 15 or 20 per cent) of the local energy of rupture remained in the most highly overstressed extreme fibers. The material may be regarded as perfectly suitable for additional straining within the primary elastic limit. The new elastic limit developed by overstraining would undoubtedly be much higher.

Effects of Overstraining

The effects which are to be described have been observed from plain plate specimens similar to *P-1* which of course is of measurable size; however, the results are applicable to any local fiber of a member regardless of size. Specimen *P-3* was overstrained nearly to its ultimate strength; the load was then removed and an interval of 16 hours rest allowed, after which the load was continued to the point of rupture. The comparative results in terms of a normal slow tensile test are as follows:

Ultimate strength (increased)	1 per cent
Yield point (increased)	47 per cent
Total energy of rupture (decreased)	21 per cent
Remaining energy of rupture	74 per cent
Total energy of rupture (loss)	5 per cent
Permanent deformation	24 per cent

A temporary overstraining of this magnitude could not possibly prove detrimental to the long life and security of the metal, providing no additional overstraining were imposed and the permanent deformation properly taken up. A metal having undergone the cold-working process of strain-hardening, as in this case, exhibits the qualities associated with greater hardness; for instance, it is tougher and more resilient as indicated by the higher elastic limit.

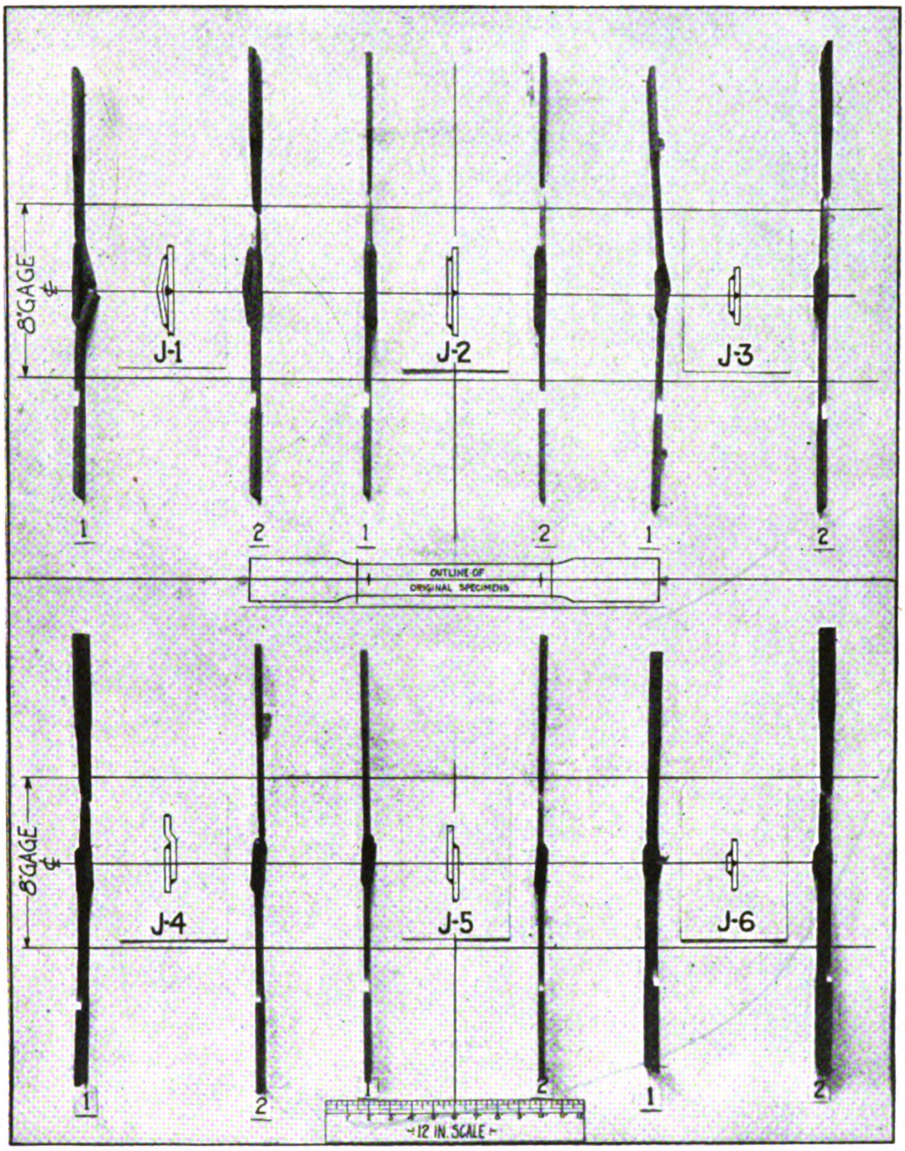

Fig. 4. Joints Having an Abrupt Eccentric Change in Section (Side View)

Specimen *P-5* was subjected to indefinite overstraining, the load being applied and removed steadily and without rest until rupture occurred. The results were a new elastic limit and yield point for each consecutive application of the load, the total permanent deformation increasing and the energy of rupture decreasing for each repetition.

The results are more comprehensive in tabular form and are given in Table I, also in the stress-strain curve (Fig. 2).

The gradual loss in ductility as given by the figures for energy of rupture may be regarded as the progressive nature of failure developed by continued or indefinite repetitions of overstrain. The energy of rupture is seen to be gradually absorbed until final rupture ensues. Each repetition produces a new and distinct group of properties. Incidentally, the quality of a metal after any amount of overstraining cannot be determined by a single test without knowledge of its previous strain history.

For comparative purposes the dotted line *a* representing a less ductile metal has been superimposed on

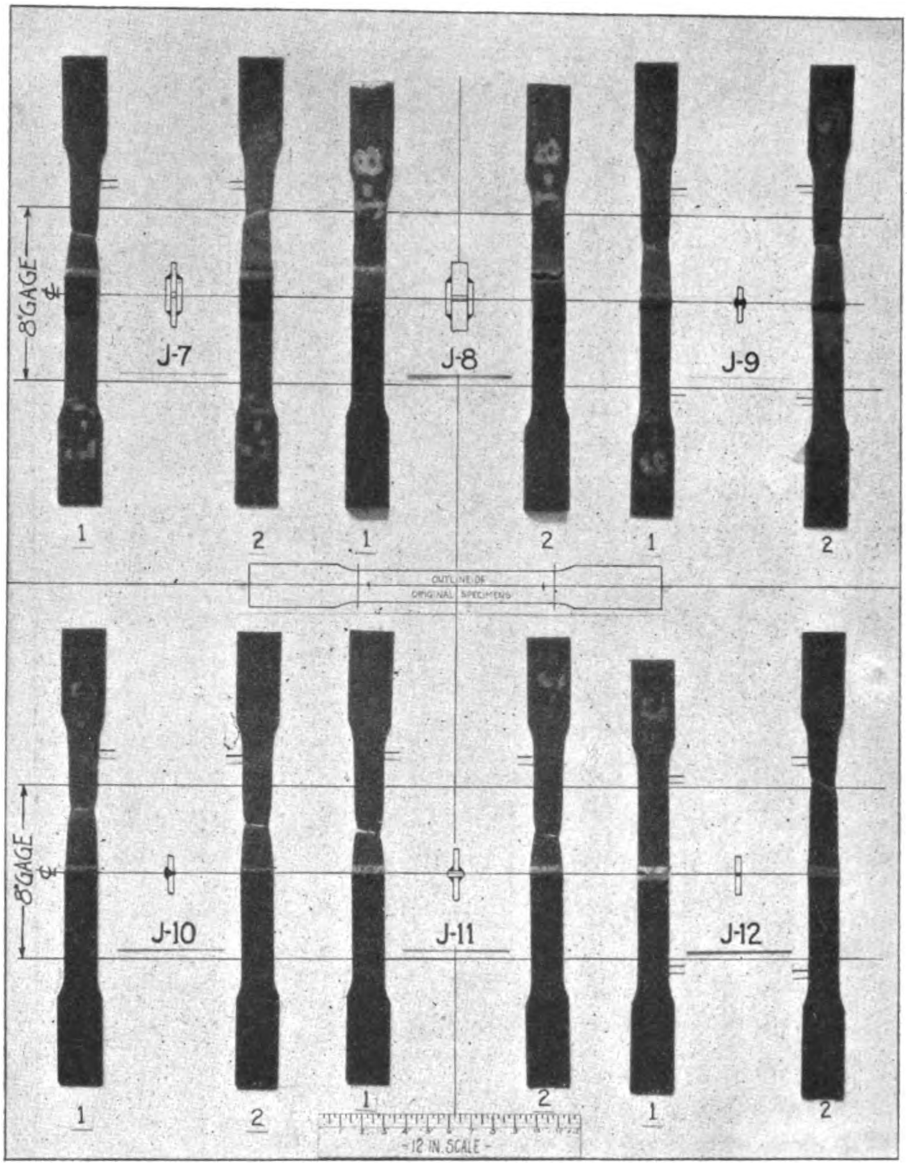

Fig. 5. Joints Having an Abrupt Symmetrical Change in Section (Front View)

TABLE I
RESULTS OF TESTS ON SPECIMEN P-5

Stress Repetition Number	Yield Point (Lb.)	Remaining Energy of Rupture (Ft-lb.)	Permanent Deformation (In.)
1	36,000	3845	0.05
2	36,700	3785	0.24
3	40,700	3540	0.31
4	43,400	3460	0.48
5	47,400	3190	0.58
6	48,700	3040	0.68
7	50,700	2650	0.83
8	52,000	2230	1.08
9	53,400	1560	1.52
10	54,000	890	1.90
11	50,700	140	2.33
		Rupture	2.45

TABLE II
COMPARATIVE RESULTS FROM LESS DUCTILE METAL

Stress Repetition Number	Yield Point (Lb.)	Remaining Energy of Rupture (Ft-lb.)	Permanent Deformation (In.)
1	36,000	1800	0.25
2	36,700	1740	0.24
3	40,700	1495	0.31
4	43,400	1415	0.48
5	47,400	1145	0.58
6	48,700	995	0.68
7	50,700	605	0.83
8	52,000	185	1.08
		Rupture	1.20

Curve *P-5*. The computed results in Table II permit a direct comparison which shows that ductility is the criterion for adaptability to overstrain.

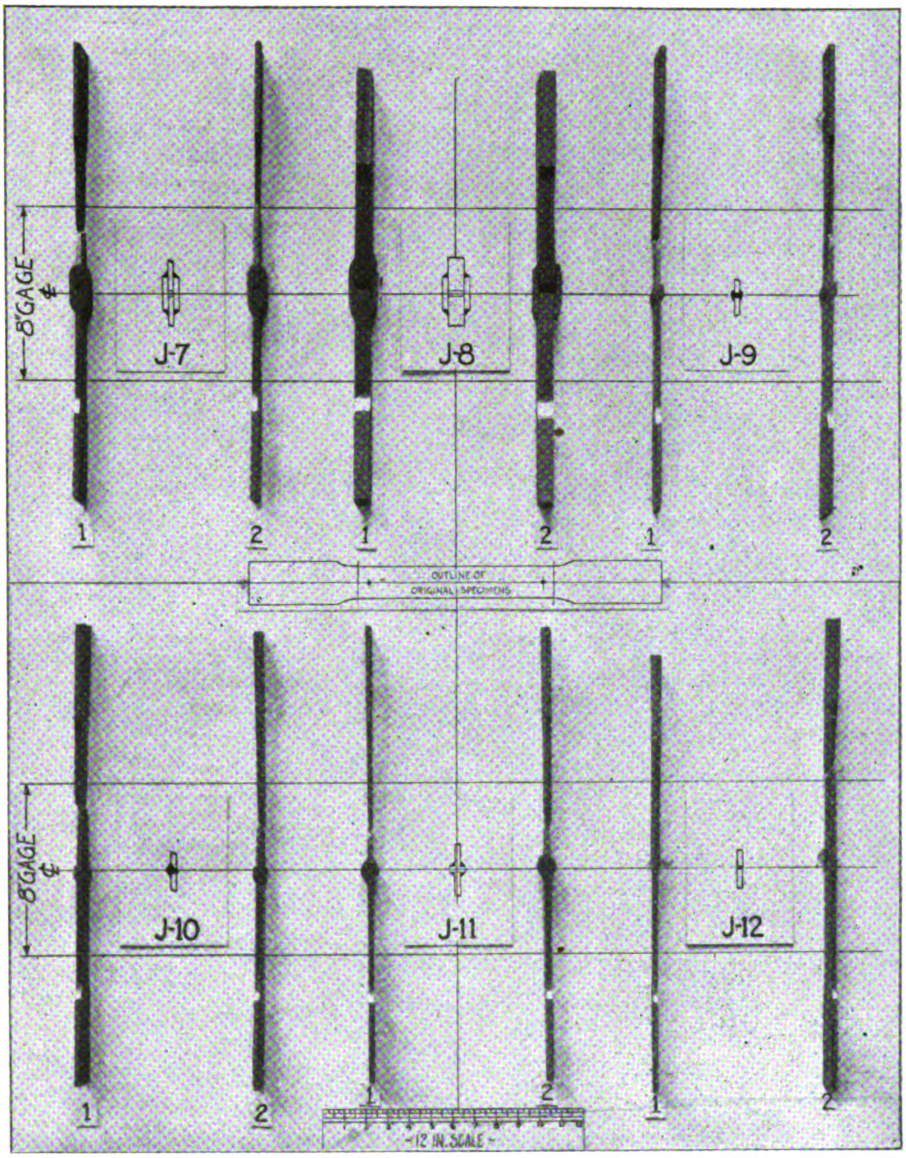

Fig. 6. Joints Having an Abrupt Symmetrical Change in Section (Side View)

As a means of comparing the ductile quality of the weld metal with that of the base metal, a special eccentric specimen was used. The general dimensions and gauge length were made the same as for the other specimens, the difference being in an eccentric offset at the center, intended to induce bending. The tests were made with the following specimens:

PE-1 and *2*......	Plain plate
WE-1, *2*, and *3*..	Finished butt weld
WE-4...........	10 per cent reinforced butt weld
WE-5...........	20 per cent reinforced butt weld

The results for *PE-1* and *-2* are:

	PE-1	*PE-2*
Ultimate strength in lb.........	60,000	60,000
Yield point in lb...............	33,400	33,400
Elongation (percentage)........	21.6	18.1
Energy of rupture in ft-lb.......	3,000	2,330

The lack of ductility in the weld metal is clearly demonstrated in the results for specimens *WE-1*, *-2*, and *-3* based on *PE-1* which follow:

	WE-1	*WE-2*	*WE-3*
Ultimate strength..	78 per cent	75 per cent	71 per cent
Yield point.......	100 per cent	100 per cent	100 per cent
Elongation........	2.7 per cent	2.7 per cent	1.4 per cent
Energy of rupture.	13 per cent	12 per cent	8 per cent

The effectiveness of reinforcing a weld against lack of ductility is evidenced by the results obtained for *WE-4* and *-5*, which are given as follows in terms of *PE-1*:

	WE-4	*WE-5*
Ultimate strength...	110 per cent	110 per cent
Yield point.........	112 per cent	112 per cent
Elongation.........	74 per cent	103 per cent
Energy of rupture...	70 per cent	103 per cent

Having only 10 per cent reinforcement, *WE-4* broke in the weld, which accounts for the lower ductility. Probably a 15 per cent reinforcement for *WE-5* would have been as effective as 20 per cent.

Plug Welds

Specimens *J-13* and *J-14* (Fig. 7) are two types of plug welded joints. These welds are not intended to develop the full strength of the plates joined, but as an indication of the strength of this type of weld. The results of test are shown in Figs. 1 and 2.

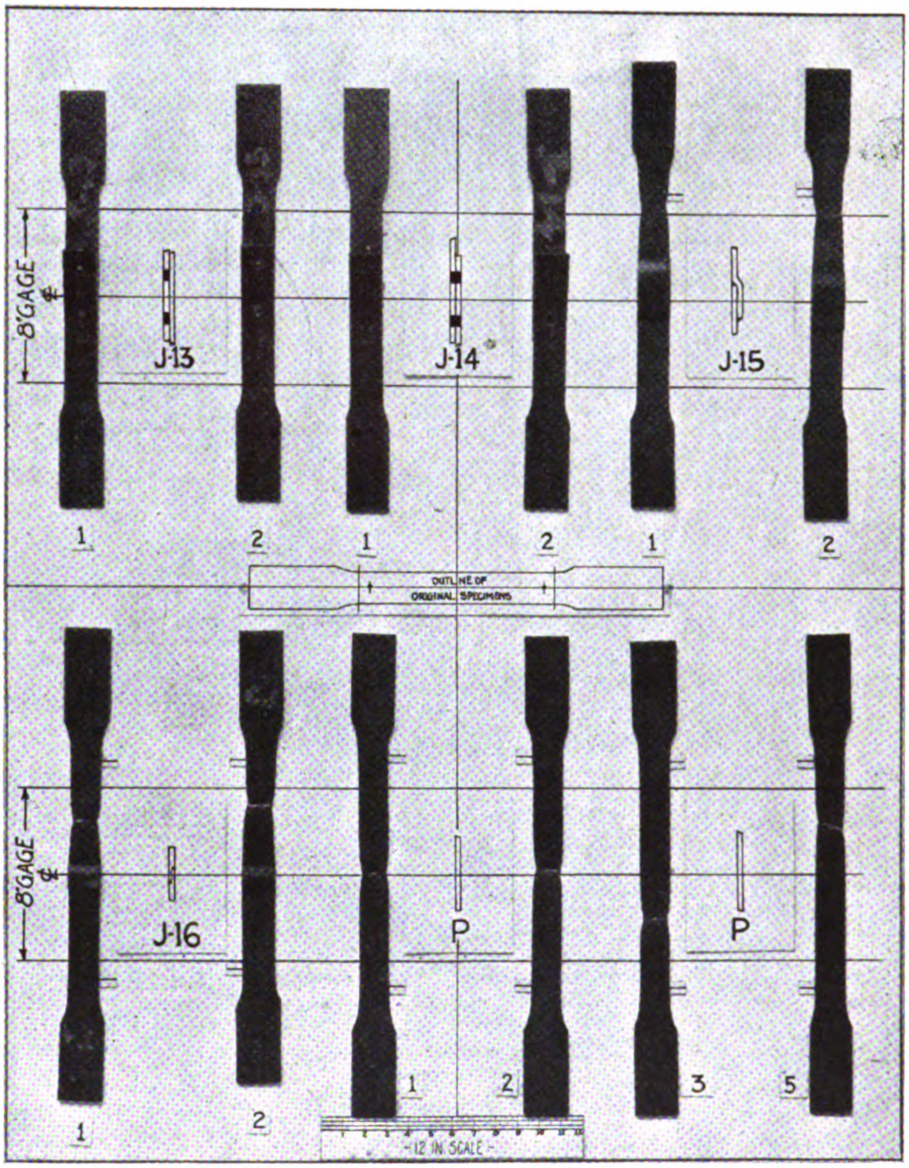

Fig. 7. Special Joints and Plain Plate Specimens for Test and Comparison

General Conclusions

Ample reinforcement and fillets of proper size offer the most practical means of insurance against failure by irregularities in the weld metal and structure and by overstraining due to incidental bending stresses.

The amount of reinforcement required for any case will depend entirely upon the degree of perfection acquired in the production of normally good welds, by any particular method; in any event the weld should be as nearly symmetrical as possible with just sufficient reinforcement to meet the strength requirements. The nearer an approach is made to the variables (*a*) and (*d*) the more nearly normal will be the results.

Ductility is a highly desirable quality in mild steel weld metal when used for structural welding.

Lack of penetration is one of the most common faults to be found in a welded joint and is especially detrimental when bending is present.

In reviewing the results obtained from the stress-strain curves, certain phenomena associated with different manners of failure were observed. The first case is most apparent in specimens *J-3*^{1} and *J-5*^{1} which failed in the welds; and *J-3*^{2} and *J-5*^{2} having failed in the plates. (It will be noted that each pair of specimen had a failure in the weld and in the plate.) When failure occurred in the weld, a higher yield point and ultimate strength with a corresponding decrease in elongation as compared with those for the plate was obtained. From the second case, quite a different result was obtained. Specimens *J-9*^{1}, *J-9*^{2}, and *J-12*^{2} failed in the plates with similar increases in yield point and ultimate strength and an exceptionally good elongation for a welded joint. There are at least two likely sources of explanation as to the circumstances out of which these abnormalities arise. They are (1) strain-hardening by cold working, and (2) rapid deformation, such as might approach the nature of impact as from a single blow. It is known that the results from increased hardness or sudden deformation will yield results similar to those obtained for the cases mentioned. With this in mind it seems reasonable to assume for the first case that with the work of rupture concentrated in the more brittle and less ductile weld metal the rapid deformation which ensued probably approached the suddenness of impact, while for the second case the process of hardening by cold working would seem most logical.

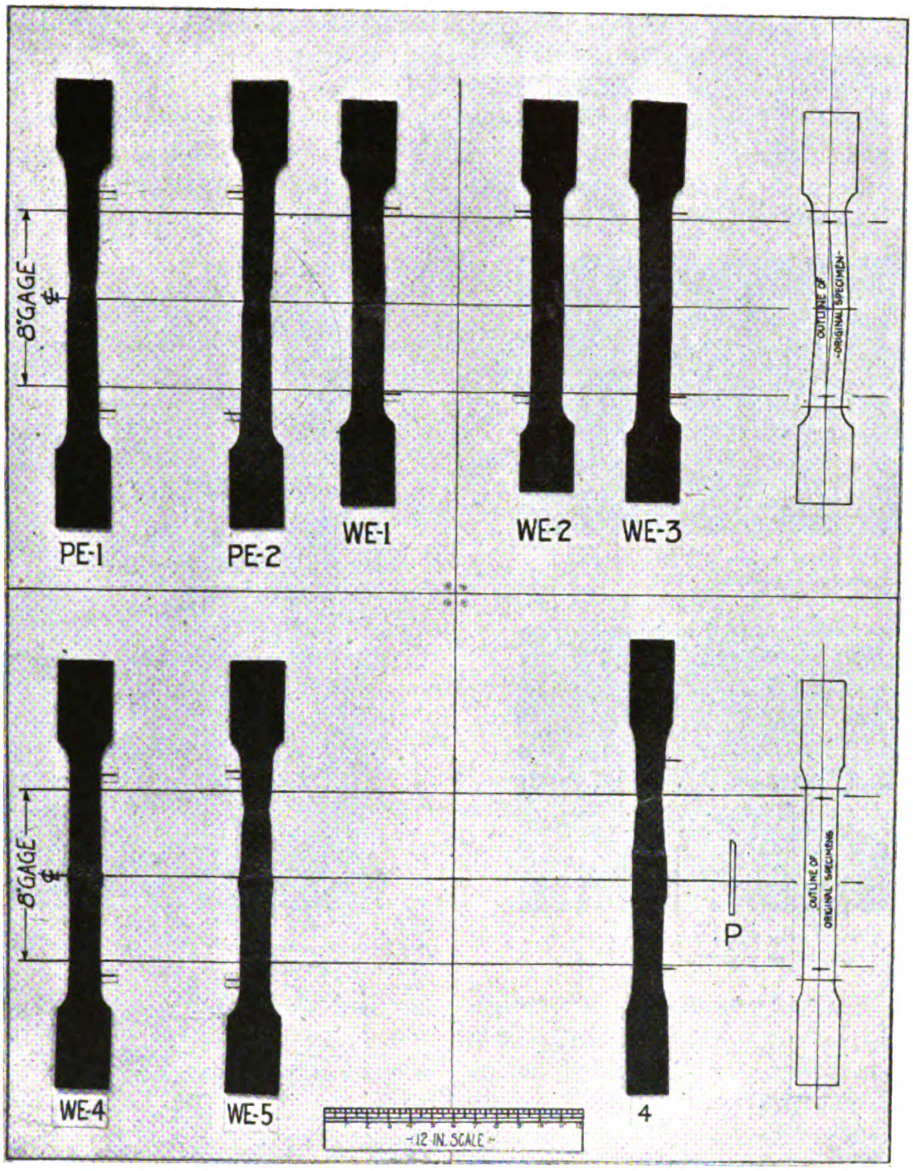
8" GAGE
℄
PE-1
PE-2
WE-1
WE-2
WE-3
OUTLINE OF ORIGINAL SPECIMEN
8" GAGE
℄
WE-4
WE-5
12 IN. SCALE
4
P
OUTLINE OF ORIGINAL SPECIMENS

Fig. 8. Special Eccentric Specimens for Introducing Bending Stresses During Tests

Lightning Tests of Power Transformers

By F. W. PEEK, Jr.
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General Electric Company

IN the last issue of the REVIEW there was a brief announcement of the first artificial lightning tests ever made on a commercial power transformer. Because of the importance and significance of such tests, it seems desirable to give further details.

For some time operating companies have felt the desirability of a transformer so designed as to be capable of safely withstanding a test lightning voltage equivalent to the flashover value of standard line insulation or gap. This coördination requires transformer insulation stronger than that line or gap insulation. Many transformers have been designed to meet these coördination requirements. Meeting these requirements has been helped to a large extent in high-voltage designs by the advent of the non-resonating principle.

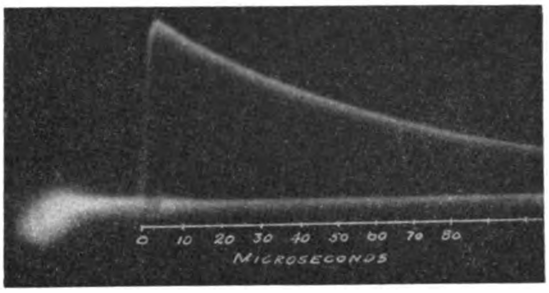

Fig. 1. A Typical Wave of One-half Microsecond Front and 55 Microsecond Tail

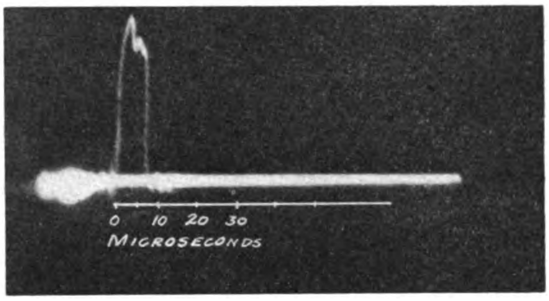

Fig. 2. The Same Wave as in Fig. 1 but Chopped by a Bushing Sparkover

It had long been thought desirable to make lightning tests on an actual commercial transformer designed for such service. However, because of the usual rush shipping schedules, opportunity did not present itself until August 8th of this year. At that time a 13,000-kv-a. transformer built for operation on the 220-kv. Fifteen Mile Falls line of the New England Power Company became available. After the usual commercial tests were completed, a short line was brought to the test room from the 3,000,000-volt lightning generator in the laboratory. At the transformer was a 63.5-in. coördinating gap, and line insulation consisting of fourteen 5¾-in. spaced units in suspension. Waves sent from the lightning generator caused the coördinating gap to spark over without damage to the transformer. The gap was then removed and the 14-unit insulator string was caused to spark over. Finally the line insulation was increased until the sparkover occurred at the bushing. There was no damage. After the lightning tests, the commercial induced-voltage and other tests were repeated. The transformer was found to be undamaged and in condition for shipment.

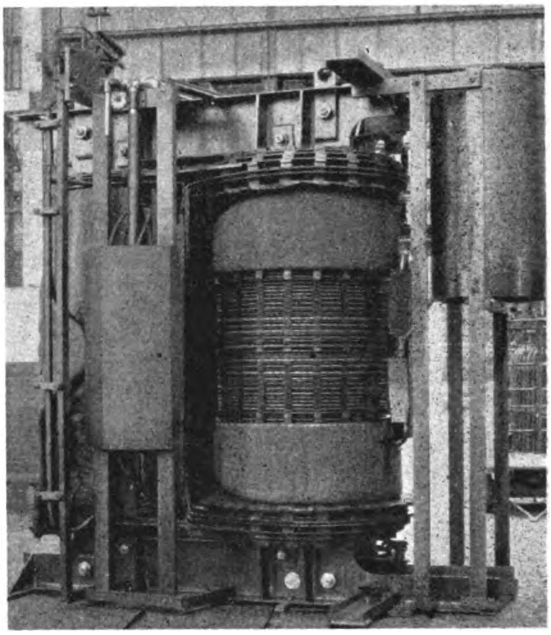

Fig. 3. Interior View of the Transformer

The transformer was of the standard non-resonating design for the 3.46 A.I.E.E. test. The lightning test is not a standard test and was not contemplated when the design was made, and no unusual precautions were taken in the design or manufacture. The waves used had a ½ micro-second front and tails varying from 5 to 150 micro-seconds. The tests were repeated on August 12 and later. The voltage distribution across the winding was measured for various lightning waves during the test and found to be uniform. This is the important characteristic of the non-resonating design.

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

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Electrical Machinery—Altitude Effects
Effect of Altitude on Power Equipment. F. H. Dutcher.
Power, June 17, 1930; v. 71, pp. 949-951.

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Factor of Safety and Working Stress. C. Richard Soderberg.
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Heating, Industrial
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Effect of Cavity Resonance on the Frequency Response Characteristic of the Condenser Microphone. Stuart Ballantine.
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Split-Core Transformer Gives Flexibility to Oscillograph. Frank E. Johnson.
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(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.)

Alternating Current Bridge Methods. Ed. 2., rev. & enl. B. Hague. 391 pp., 1930, N. Y., Isaac Pitman & Sons. $4.50.
("A theoretical and practical handbook for the use of advanced students." This volume on the measurement of inductance, capacitance, and effective resistance at low and telephonic frequencies is a revision and enlargement of the first edition, which appeared in 1923. The book is intended for practical use, and emphasizes the experimental side of the subject, but an effort has been made to explain the theory underlying the a-c. bridge network. The volume opens with a short chapter on fundamental principles, followed by another on the symbolic theory of alternating currents and its application in bridge networks. Then comes an extended consideration of the various types of measuring apparatus, and of the classification of bridge networks. The concluding chapter treats of the choice of a bridge method and precautions to be observed when using it. A useful feature, especially for research workers, is the inclusion, in the form of footnotes, of numerous and complete bibliographic references.)

Geschichtliche Einzeldarstellungen aus der Elektrotechnik. Vol. 2: Die Geschichtliche Entwicklung der Hochspannungs-Schalttechnik. Max. Vogelsang. 176 pp., 1929, Berlin, Julius Springer. 21.00 R. M. (paper.)
(This is the second volume of a series, issued by the German "Elektrotechnische Verein," dealing with the history and development of the different phases of electrical engineering practice. It is devoted entirely to a consideration of the high-tension circuit breaker, from the very beginning of the era of electric power, in the eighteen-eighties, to the year 1912. It is but natural that the European developments in general, and those of Germany in particular, are given the major attention. However, achievements on this side of the Atlantic are also recorded, especially those of the larger manufacturers of electrical equipment in the United States. Copious footnote references to historical literature enhance the value of the work.)

Modern Lighting. Frank C. Caldwell. 386 pp., 1930, N. Y., MacMillan Co. $4.25.
(A general text on the elements of electric lighting theory, design, and equipment. Treats the fundamental theory and units, the requirements for good illumination, the various electric light sources, illumination measurements and the instruments therefor, lighting equipment, and the design of lighting installations. Several of the later chapters are devoted to lighting for special applications, such as factories, offices, residences, streets, etc. A chapter each on light projection, radiation and color, and signs and signals are provided. The treatment is mainly descriptive, theoretical considerations being reduced to a minimum. Many illustrations of lighting equipment and lighting installations are included.)

Selektiv-Schutzeinrichtungen für Hochspannungsanlagen, mit Anleitung zu Ihrer Projectierung. M. Walter. 128 pp., 1929, München, R. Oldenbourg. 7.00 R. M. (paper.)
(The author outlines briefly, in this German booklet, the different types of selective protective devices for high-tension systems. The work is intended for both student and engineer, and is based on the author's experience of many years in design practice. Three chapters are devoted to the study of short-circuit phenomena, and two chapters to methods of practical design, including instructions for planning complete protective systems. A bibliography of 35 entries is included.)

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SCHENECTADY, N. Y.

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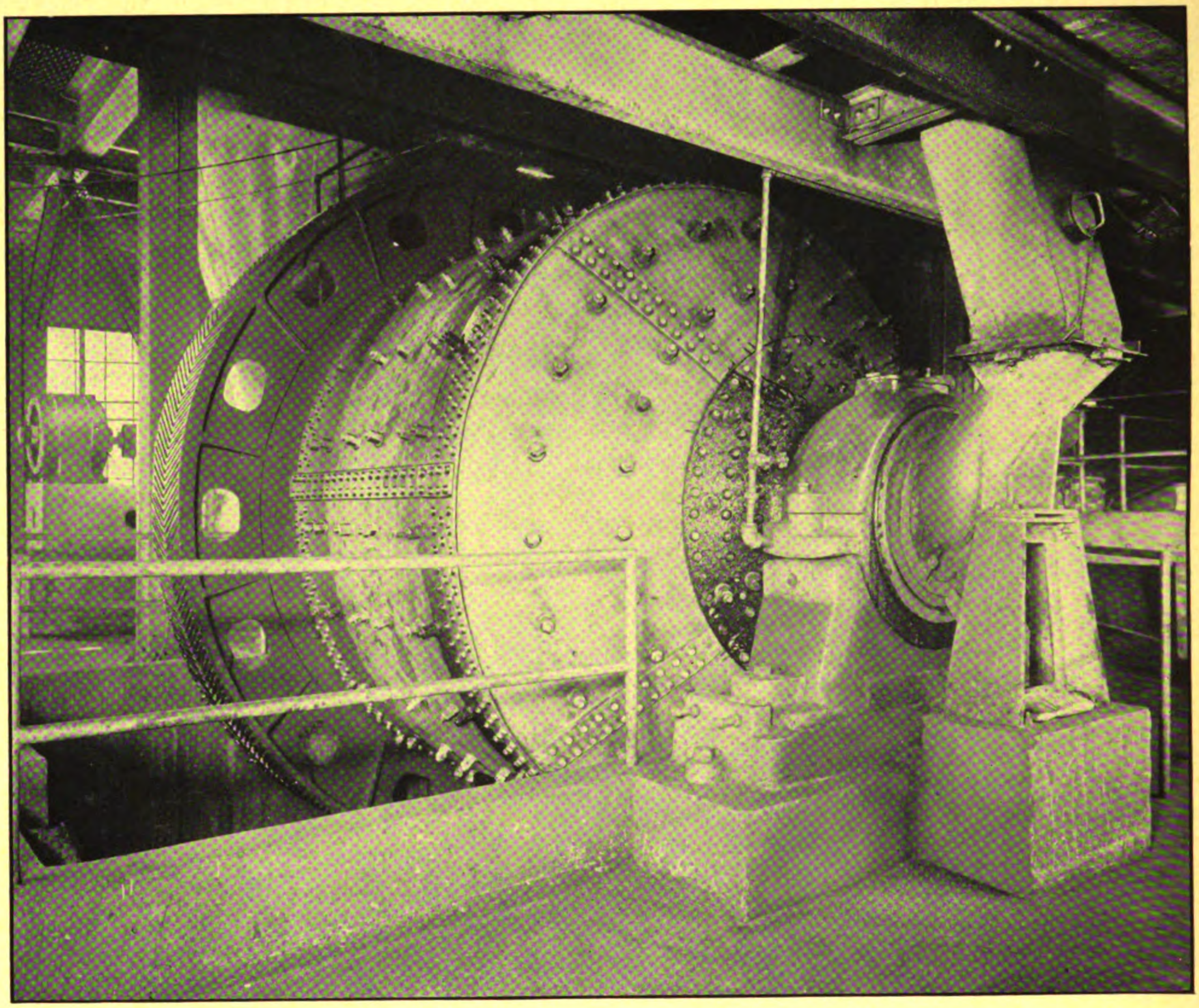
GENERAL ELECTRIC
REVIEW

VOL. 33, NO. 11 NOVEMBER, 1930

"The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds, they shape themselves and go."
—*Tennyson*

Shovels, however, work quicker than Nature when the mountain contains copper!
(*See p. 600*)

In This Issue: *Temperature Effects on Turbine Materials* *Corona Losses* *X-ray Apparatus* *Short Cables and Voltage Surges* *Elevator Calculations* *Series Capacitors* *Circular Corrugations* *Current Transformers* *Cupola Blowing* *Mining Equipment*



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monthly by *INDUSTRIAL ARTS INDEX*, and weekly and annually by *ENGINEERING INDEX*; and abstracted monthly by *SCIENCE ABSTRACTS*

W. D. COOLIDGE

Associate Director of Research Laboratory, General Electric Company
Father of the Modern High-power X-ray Tube

GENERAL ELECTRIC REVIEW

Vol. 33 November, 1930 No. 11

X-RAYS

In reading Dr. W. D. Coolidge's Caldwell Lecture on "The Development of Modern X-ray Generating Apparatus," one is struck by the tremendous changes which have taken place in this field during the thirty-five years which have elapsed since Wilhelm Konrad von Röntgen, then professor of physics at the University of Würzburg, made his epoch-making discovery of x-rays.

Referring to the x-ray tube itself it is, indeed, a far cry from the earliest tube used by Röntgen, the old Crookes' tube dating back to 1878, to the modern tubes. Many workers in many lands have helped in bringing about this transformation, and we marvel at their work.

It is, however, easier to appreciate the work than to recognize its significance to the world.

X-ray tubes have been the most potent tool in ushering in the "New Physics."

Ever since we first read Silvanus Thompson's beautiful classic, "Light Visible and Invisible," we have learned to regard all sorts and kinds of electromagnetic radiations as "Light."

The limits that natural evolution imposed upon our human sense organs handicapped man in his perpetual struggle to gain knowledge of his own environment and of the external physical universe, until the time when our imaginations became wedded to scientific research and revealed to our senses sounds that our ears could not hear and lights that our eyes could not perceive.

We believe that man has gained more knowledge of the physical universe by analyzing and studying the various forms of light in our now widespread energy spectrum, with their almost infinite series of frequencies and wavelengths, than by any other means. So it is of special interest to note that throughout long pages of history man has regarded the word "light" as synonymous with knowledge and understanding. Thus, King David prayed, "O, send out thy light and thy truth." Omar Khayyam warbled "the one true light kindling to love"; and mankind in general, both in metaphor and idiomatic speech, has used such expressions as "to see the light" and "to enlighten our darkness."

The only light apparent to King David and to his day and to the long centuries before and after his age, was that single octave of light which is visible to the human eye. Even their knowledge of that one octave was limited to an almost entire ignorance. They were surrounded by all the marvels that have since been discovered, but it was then a case of "eyes that see not and ears that hear not."

Today, man, with an inquisitiveness and trained intelligence, which in our varying moods we at times regard as trifling, when compared with the possibilities of human imagination and understanding, and at other times regard as almost godlike, has discovered many forms of light that throughout the ages have kept the universe a-humming with their many mysterious properties and multitudinous functions, but which previously had been unknown to man.

Beyond the red of our visible spectrum man has now discovered the infra-red; beyond the infra-red, those many octaves of Hertzian light or "wireless waves," which may measure miles from crest to crest. These long waves have verily gilded the world with a new light, brought all human beings into speaking distance with one another, and made it possible to illuminate the whole world with the light of knowledge. Beyond the violet he has discovered the ultra-violet; beyond the ultra-violet, those many octaves of x-rays or Röntgen light—beyond these the gamma rays, sent forth from radio-active matter and, again, beyond these, those cosmic rays coming to us from interstellar space, whose origin is still held a secret in the outermost reaches of the heavens, whose penetrating power is unthinkably great, and whose future services to mankind may prove to be limitless.

With each new form of light discovered, the horizon of man's knowledge has been extended, but we often think that the discovery of x-rays was the most sublime contribution up to the present as it has led to so many other discoveries, one after the other, each more marvelous and perplexing than the last.

Röntgen's far-famed discovery of these exceedingly short waves in the ether, with their high penetrating power—waves so short in fact that more than two hundred and fifty millions of them, measured from crest to crest, occupy no more length than a single inch—amazed the world. The crowd gaped open-mouthed, and many an elderly spinster considered lead linings for her painfully modest garments, of "the gay nineties" vintage, when the daily newspapers announced that one's bones, and other invisible things, could be laid bare to the gaze of the curious. This mighty discovery, which was the result of a magnificent piece of research work by an investigator of the first order, had a more useful and triumphant effect than even the new light, and new hope, it brought into the rooms of the sick and diseased—it stimulated the imaginations of scientific minds.

It was interest in Röntgen's great discovery that started Henri Becquerel on his classical researches on uranium, and it was these in turn that stimulated Madame Curie to the celebrated researches that led to her magnificent discoveries of polonium and radium, and gave to an awe-struck world not only two new and perplexing elements, but also the glorious new science of radioactivity.

The story now becomes too widespread to review, even briefly, or to give a mere list of the names of those incomparable physicists, who, laboring in many wide realms of physics and natural philosophy, were stimulated to new investigations with the new magic tools of x-rays, and radioactive matter. So for reasons of brevity the names of many illustrious men can be made conspicuous here only by their absence.

In the radiance of these new lights matter promptly became disembodied, the atom became divisible, and the interior of the atom became a veritable research laboratory, and was soon compelled to give up some of its secrets. Old theories had to be discredited and new theories propounded.

And so, nourished by these new discoveries, the tree of human understanding grew, ever producing new branches, and each branch producing a multitude of leaves, all absorbing new light and new knowledge.

Until the year 1912, x-rays could not be classified as a form of light. It is true that they had been polarized by Barkla in 1906, but they had not been reflected, or refracted—the critical tests that every newly discovered agitation in the ether must pass before it can be graduated into a position in the spectrum of electromagnetic energy.

In 1912, Laue, a young Swiss physicist, possessed of a superlative imagination, knowing that man could not rule his diffraction gratings with much more than 200,000 lines per inch, had the delicious impudence to woo Dame Nature herself. With wonderful tact, vision, and understanding he courted Dame Nature, and asked her if in all her magnificently ample workshops she had made a grating with at least a thousand lines for every one that man, with his best skill and artistry, could rule. Dame Nature answered, "yes"—She so often responds to those who are in real earnest and persist.

The secret lay in crystal structure. Nature builds her crystals with the Creator's little bricks, laid all orderly layer upon layer, each layer but one single atom thick.

It is a long story, but one with a magnificent conclusion.

Laue diffracted x-rays with Nature's own diffraction grating—the crystal.

Since then, x-rays have been reflected and refracted, but that is another story.

These magnificent researches of Laue, Bragg, and others proved beyond doubt the reality of the molecule and atom, banished the mystery of the nature of x-rays, and led to assigning this new light to its proper place in the spectrum.

Some discoveries are like sparks in a barrel of gunpowder. Laue's work inflamed the imagination of Henry G. J. Moseley—Moseley that brilliant young English physicist who in the name of patriotism and duty stopped a bullet at ill-fated Gallipoli. And here, dear readers, bare your heads, for one small bullet stilled an imagination that was in tune with the infinite. Before he heard and obeyed his country's call, Moseley conceived that marvelously clever idea of using each element in the periodic table, in succession, as a target in his x-ray tube. He photographed the x-ray spectrum of the elements and he gave us our atomic numbers—a series of numbers that, taking hydrogen as 1 and uranium as 92, gives all the elements their respective places in the universe's great cosmos, arranged in order, not in chaos, arranged in their ascending complexities, complexities accrued by each additional electron. And here is a single paragraph, written with affection and respect of a man who ought to have a monument and a biography.

But, what of these researches and researchers?

They have given us the supremely magical and all-important new sciences of crystal structure and radioactivity.

They have made the molecule and atom as much of a certainty as the sun, the moon, and the stars.

They have shown the arrangement of the atoms in the crystals.

They have proved beyond doubt the electrical nature of matter.

They have shown that the atom is electrical in nature, is held together by electrical forces, and can be disrupted by electrical forces.

They have proved that Nature marshals her electrons and protons in regular sequence in her elements; from hydrogen, the lightest, to uranium, the heaviest.

They have proved the word "atom" a misnomer, because the atom is divisible.

They have made a living entity of the electron.

They have led to the propounding of the Quantum Theory.

They have taught us that energy is atomic—that energy is granular in structure and electrical in nature.

They have given us knowledge of that primordial "stuff" from which all forms of matter have evolved.

They have given us a new conception of the universe.

They have lent us a new hope that some day man may prove that those great fundamental entities—matter, ether, and energy—working in the vast realms of space and time, may reveal the secret thus far hidden, that all are different phases of a great "oneness" in a greater universal plan.

The new discoveries seem to lend evidence in support of the corpuscular theory of light today, and, tomorrow, seem to be giving evidence on behalf of the wave theory; leading some famous physicists to feel that they can be faithful to neither, but rather must be fickle enough to flirt with each theory on alternate days.

They sometimes give us the impression that the physicists whom we used to regard as constantly taking things from the realms of metaphysics and planting them in the realm of physics are reversing themselves. It now often appears that "things" of which we thought we had a mental picture, and could conceive their mechanisms, are being taken from the realm of physics and thrown back into the hazy reaches of metaphysics.

They have extended our knowledge and shown us how much further our knowledge must be extended.

. . . .

After all, what are these x-rays?

Now, the beta rays from radium, the cathode rays, and the little electrons are one and all the same entity parading under different aliases. They are simply particles of negative electricity.

Here we shall, with due apologies, crib a line or two from Cambridge—from a song composed and sung by a Cavendish Lab student—sung to the tune of "The Interfering Parrot." It is a particularly clever song on Maxwell's equations but it is long. So, we shall steal but a few lines to suit our own purpose.

"The corpuscle won the day
And in freedom went away
And became a Cathode Ray.
But his life was rather gay,
And he went at such a rate,
That he ran against a plate;
When the aether saw his fate
Its pulse did palpitate."

Now consider an x-ray tube, the cathode ray of the song is the streams of electrons, the plate is the target, the palpitations are the x-rays.

Whenever an electron traveling at high speed strikes a solid object, x-rays are produced.

To avoid confusion, we shall not consider the older gas tube, but will confine our remarks to a modern Coolidge tube. It consists of a source for producing electrons, a target, and a highly evacuated bulb or tube.

In a Coolidge tube, the hot cathode in a high vacuum gives a perfectly controllable source of electrons.

The more prolific the source of electrons, the more x-rays are produced.

The denser the target, consistent with the required temperature characteristics, the more suddenly will the electrons be stopped and the more x-rays will be produced.

The higher the voltage, the greater the speed of the electrons, and the more penetrating the x-rays.

It is when we realize what a powerful implement the modern x-ray tube is in the fields of physical research, medicine, and industry, and remember that it was Coolidge and his fellow workers in the great Research Laboratory at Schenectady, who after years of labor produced the most controllable source of electrons, the best target, and attained the highest voltage, thus giving us the most controllable and most powerful source of x-rays, and x-rays of the highest penetrating power thus far reached, that we feel a word of acknowledgment and congratulation is in place.

We remember, somewhat dimly it is true, a picture; we believe a print of it at one time hung in the Engineers' Club in New York. It portrayed some kind of a feast to all those engaged in building King Solomon's temple. The toolmaker, noble of face, of fine physique, and with brawny arms, had usurped (?) the seat of honor. The stone masons, the hewers of wood, the drawers of water, the artists and the artisans alike, uttered the old cry of "Crucify him! Crucify him!" Solomon in all his wisdom heard his plea that the seat of honor was his by right as none could have done their work without his skill in fashioning the tools with which they worked. Solomon honored the toolmaker, placed a crown upon his head, and proclaimed his right to the seat of honor.

To our minds there is just about as much difference between the simple tools with which King Solomon's temple was built and the tools used in our modern temples of science as there is between the ages of which they are symbolic.

So we honor and salute, not alone the makers of our modern tools, which have proved the "open sesame" of our present age, but we pay homage to the institution that nourishes both the work and the workers.

J. R. H.

Electrification of the Utah Copper Mine

By RAY CORFIELD

Assistant Engineer, Utah Copper Company

> *This contribution shows the reasons why electric shovels and locomotives are used in one of the largest and most interesting mining undertakings in the world.*
> —EDITOR

THE history of this mining venture dates back to 1863, when the ore body was first discovered in connection with underground silver mining. Immense quantities of low-grade copper ore were known to exist, but it was not considered economical to mine them. Copper at that time was selling at twelve cents per pound, making it necessary to mine on a very large scale if profits were to be realized. Several mining engineers reported favorably on the Bingham copper deposits, all conceding that a large capital investment would be required. The raising of this capital is now history, but the realization of the dream of those copper pioneers is now a reality, and has exceeded the fondest hopes of any of them in magnitude.

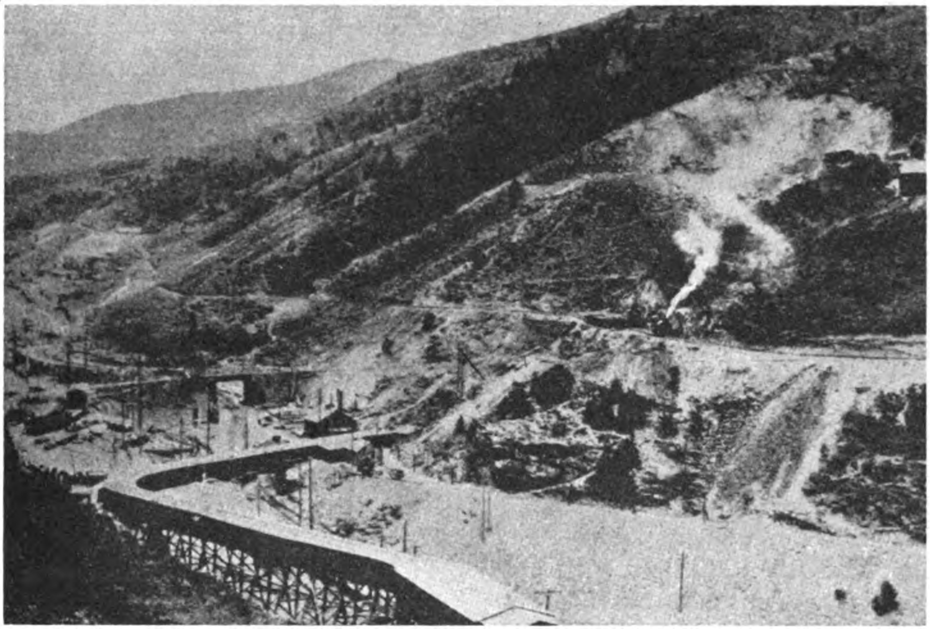

Fig. 1. First Steam Shovel at Bingham

The Utah Copper Company was organized in 1903, and plans were made for opening this great copper deposit on a large scale. From the beginning, an open-cut project with standard gauge rail facilities was contemplated. The first steam shovel, illustrated in Fig. 1, was put in operation in 1906 on what appeared to be an ordinary looking mountain covered with small timber and heavy underbrush. The ore body was covered with an overburden of decomposed rock, varying in depth from 75 to 200 ft., and it was necessary to remove this capping and deposit it in the nearby ravines before ore could be mined. After twenty-four years of operation the property appears as shown in Fig. 2. The present mine site covers approximately 725 acres and to date over 200,000,000 tons of overburden have been removed, and an almost equal amount of ore has been transported to the concentrating plants which are located twenty miles from the mine.

The company owns and operates its own railroad, which was built during 1910 and 1911. This road passes along the foothills, ascending on a two per cent grade into Bingham, the last five miles running through very rough country where it was necessary to build three steel viaducts, varying in length from 640 to 690 ft., and in height from 188 to 225 ft. Four tunnels, having an aggregate length of nearly a mile, were bored through solid rock. During this construction approximately 1,680,000 cubic yards of material were moved, divided as follows: solid rock, 747,000 cubic yards; loose rock, 618,000 cubic yards; earth, 315,000 cubic yards. This railroad is equipped with the most modern signaling devices, including remote-controlled switches and centralized traffic control.

Early in 1921, an economic study of mining methods was made with the idea of reducing costs. Drilling, blasting, and track laying were being done at a very fair cost, while the loading and transportation was a large percentage of the total cost. A detailed study of the loading operation was made and certain costs predicted for electric drive. Steam shovels had been in operation for years and accurate cost records kept. These predicted costs when compared with the established steam costs led to the purchase, in 1922, of two railway-type electric shovels, one being driven by alternating-current motors while the other was driven by direct-current motors. Comparative tests were made between the two types of electric and steam, and it took very little time to convince all concerned of the superiority of either type of electric shovel over its steam competitor. Considerable difference of opinion existed regarding the merits of a-c. and d-c. drive for this service. A comparison of the characteristics, shown in Fig. 3, indicates that the d-c. drive, with Ward-Leonard control, approaches the steam characteristic very closely, giving the necessary flexibility, the power input and maximum peak being lower and the power-factor higher. At present there are eight shovels equipped with a-c. drive and fifteen with d-c. drive.

Three types of d-c. motors are available for shovel drive, *viz.*, shunt, compound, and series wound. Which of these motors is best adapted depends on the nature of the material to be handled and the speed requirements. In general, it may be said that the separately excited compound-wound generator furnishing power to series-wound hoist motors and shunt-wound swing and crowd motors is best suited for general application to railway-type shovels. Typical graphic charts, showing the power required, peaks, and general character of the duty cycle, are shown in Fig. 4, for the d-c. drive, and in Fig. 5, for the a-c. drive. These curves are not intended to be comparative but indicate quite clearly the severity of the duty cycle and the necessity for using the most rugged type of electrical equipment available.

It should be noted at this point that the electrification of shovels has been directly responsible for an improved mechanical shovel, as the torque obtained from electric shovels is greater than from steam engines, making it necessary to strengthen the underframing, gearing, and other structural parts of the shovel. This increased strength and ruggedness means fewer mechanical delays and hence is a contributing factor in electrification economies. Fig. 6 shows an electric shovel at work, and Tables I and II summarize operating economies and results of one year's operation with both types of electric shovels.

Fig. 2. General View of the Mine

It may be said at this time that the present electric shovel is a highly developed and simplified piece of equipment, and that the most important part of an electrification project is getting power to the shovels, and determining the type and capacity of substations. On a mining property, where conditions change rapidly, outdoor stations are preferable, as they may be easily moved. Provision should be made to have one bank of transformers spare, for large installations. At Bingham, two shovel substations are provided, each containing six 400-kv-a. transformers, and the necessary switchgear. Each station is arranged with a paralleling bus, and the two stations can be tied together when necessary through the trunk lines, which are built in duplicate and completely encircle the mining area. These trunk lines are brought as close as possible to the ends of the benches. The problem of getting power across the bench required considerable study and experimenting. It was not considered feasible to carry any exposed wires on the levels as these lines have to be moved every twenty-five days, and are in the blasting zone. The secondary voltage at the shovel substations is 5500 volts, and as the altitude is about 7000 ft., the use of high-voltage, three-conductor cables was questioned; however, as this seemed to be the only suitable means of transmission, several 500-ft. lengths of rubber-covered cable were purchased and installed. After several weeks, these cables showed signs of distress and were replaced by cables having a static shield made up of copper gauze. This retarded somewhat the effects of ionization, but owing to the fact that splices had to be made in the cables, bonding of the static shield was difficult and unless properly done caused a breakdown approximately two feet on either side of the splice. Cable manufacturers were trying to develop a cable that was free from electrical trouble without using any shielding and at the same time having good mechanical qualities. In the meantime, three single conductors in conduit were tried. This system did not work out, as the single-conductor cables would break down and ground to the conduit, burning large holes in it, making it necessary to replace wires as well as conduit. At this time permission was obtained to try a section of aerial line on the bench. This trial line was erected on wood poles set in the customary manner. Composition insulators were used on account of their

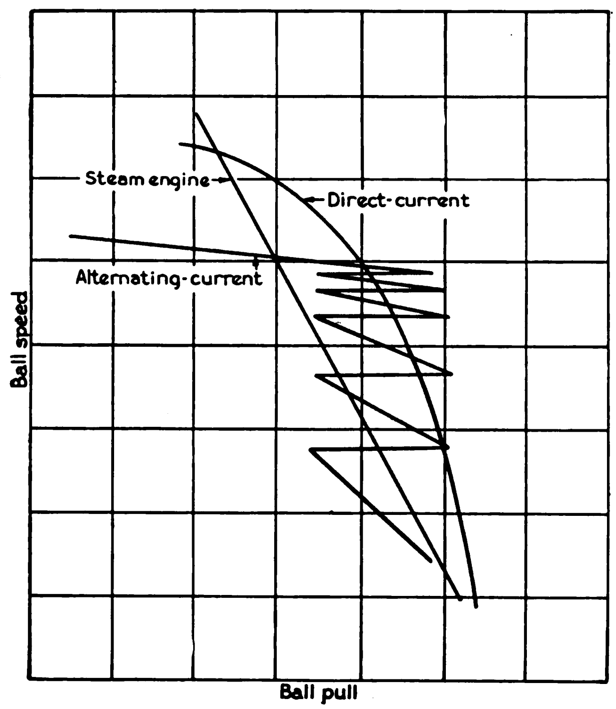

Fig. 3. Comparative Shovel Characteristics

TABLE I

COMPARATIVE SHOVEL COSTS

Steam	Per Cent	Electric	Per Cent
Engineer	100	Engineer	100
Craneman	100	Craneman	100
Fireman	100	Electrician	51.1
Coalman	100	Electrician helper	51.8
Pitman	100	Pitman	100
Watchman	100	Watchman	0
Total operating labor	100	Total operating labor	76.2
Coal and water	100	Power	17.5
Packing and oil	100	Packing and oil	34.0
Total operating material	100	Total operating material	20.4
Repairs	100	Repairs	21.5
Total cost per ton	100	Total cost per ton	37.2

TABLE II

ELECTRIC SHOVEL PERFORMANCE, 1928

Type of Shovel	Material Handled	Tonnage	Kwhr. Used	Tons Per Kwhr.
A-C	Ore	3,613,720	2,380,041	4.421
A-C.	Waste	6,908,460		
D-C.	Ore	12,942,350	4,202,539	5.055
D-C.	Waste	8,301,710		
Totals		31,766,240	6,582,580	4.826

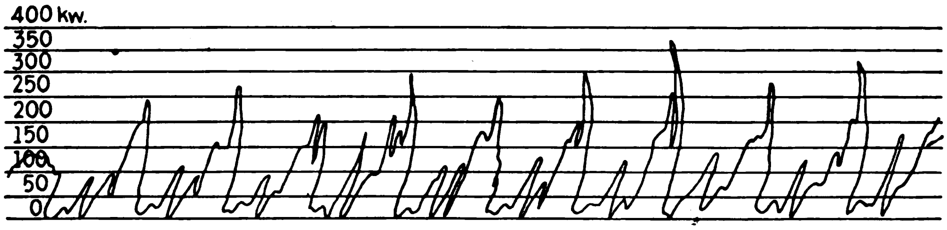

Fig. 4. Power Input, Direct-current Shovel

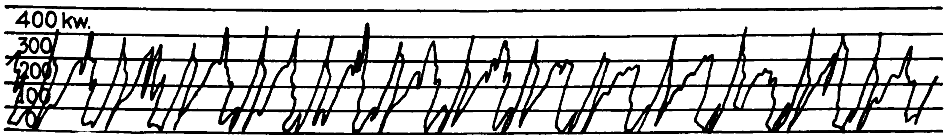

Fig. 5. Power Input, Alternating-current Shovel

unbreakable qualities. An examination of this line, after several weeks' operation, revealed a number of shattered poles and cross arms, and the insulators were completely covered with mud, but no electrical delays occurred. This type of construction proved to be what was required from an electrical standpoint, but the fact that it was costly to move every 25 days led to the design of a portable structure in the form of a steel tower 25 ft. high and six feet square at the base, weighing approximately 800 lb. These structures were very satisfactory, and now a modified type of tower is used on all benches requiring a power line.

The results of shovel electrification were very gratifying and led to a study of the haulage system.

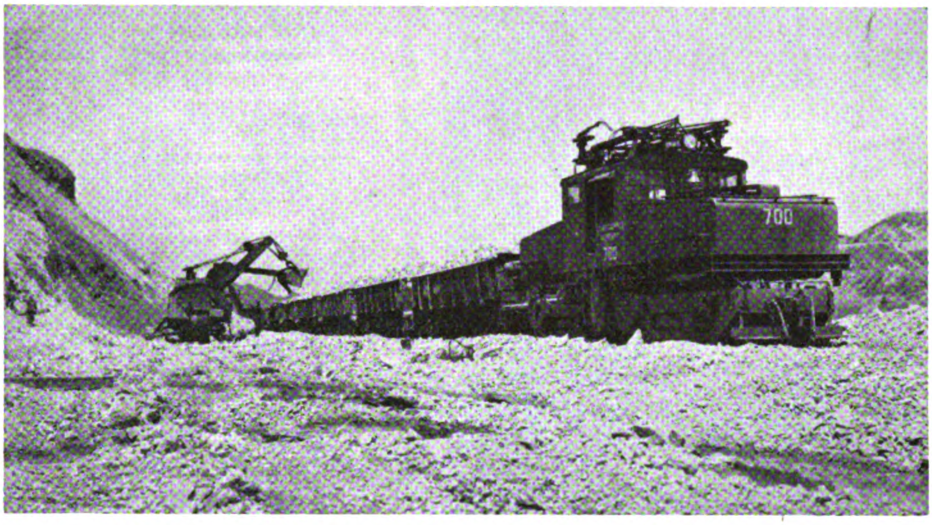

Fig. 6. Electric Shovel and Electric Locomotive at Work

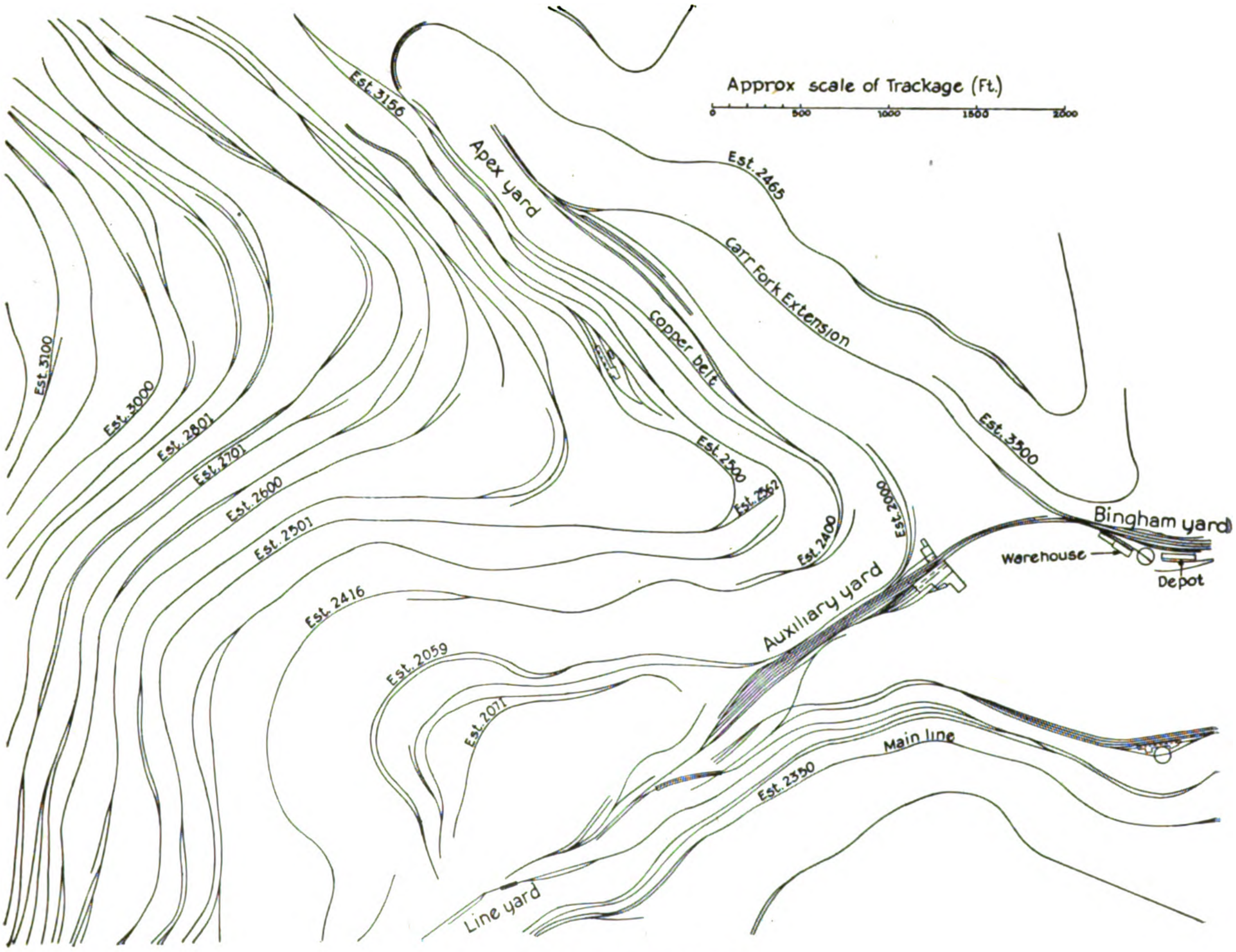
Approx scale of Trackage (Ft.)
0
500
1000
1500
2000
Est. 3156
Apex yard
Est. 2465
Carr Fork Extension
Copper belt
Est. 3100
Est. 3000
Est. 2801
Est. 2701
Est. 2600
Est. 2501
Est. 2500
Est. 2562
Est. 2400
Est. 2000
Est. 3500
Bingham yard
Warehouse
Depot
Auxiliary yard
Est. 2416
Est. 2059
Est. 2071
Main line
Est. 2350
Line yard

Fig. 7. Map of Haulage System

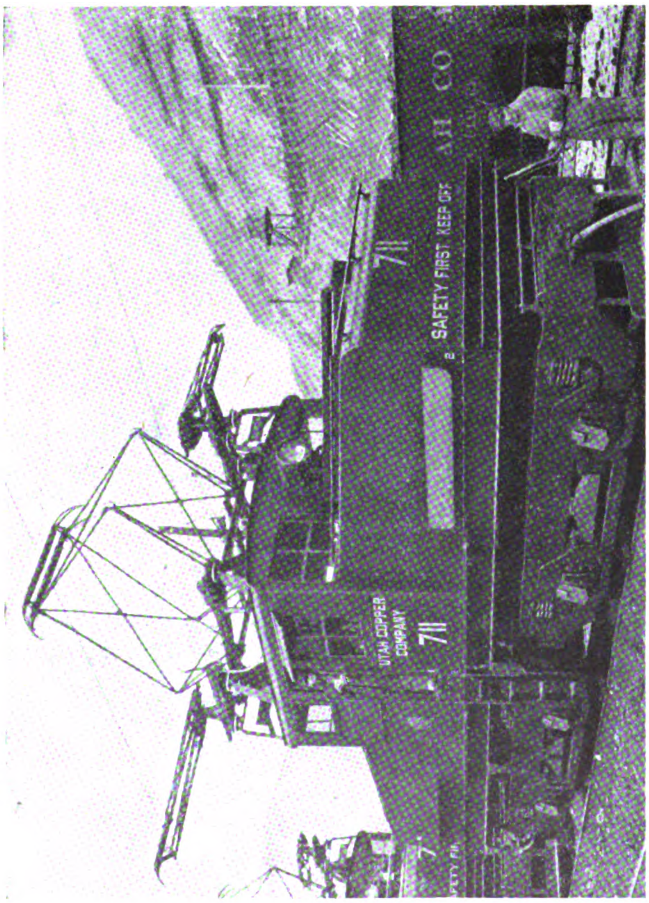
711
SAFETY FIRST KEEP OFF
UTAH COPPER COMPANY
711

Fig. 8. Typical Electric Locomotive

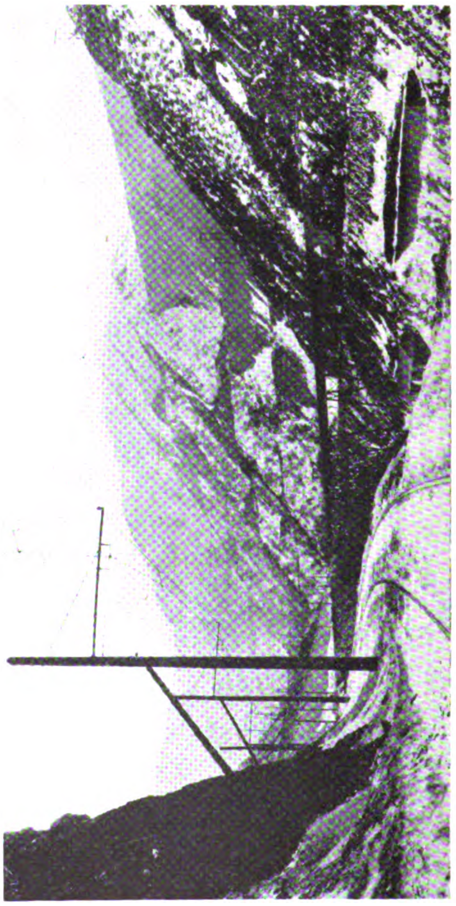

Fig. 9. Special Curve Construction

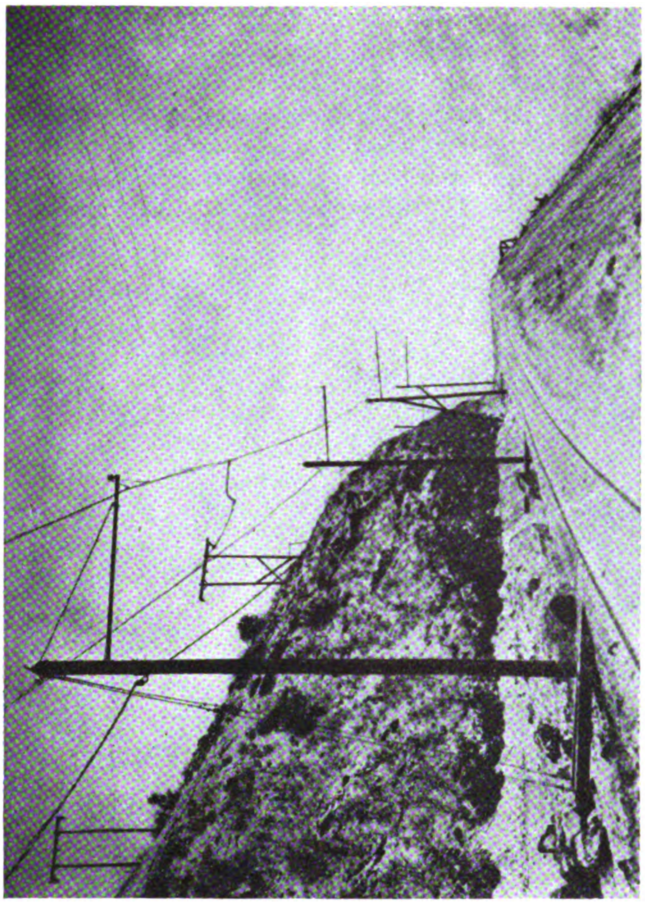

Fig. 10. Overhead Construction on Fills

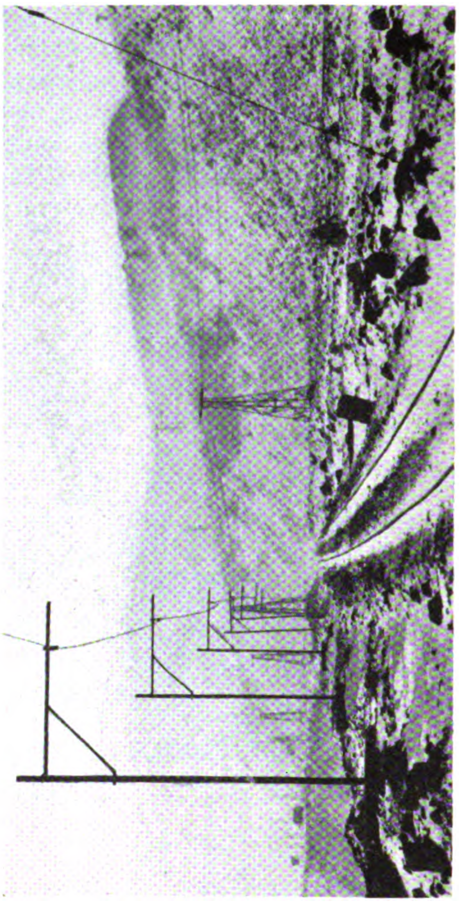

Fig. 11. Trolley Construction on Benches

Fig. 7 shows a part of the haulage system. All switchbacks are on a four per cent grade, equated for curvature, and end in tail tracks which are level. Curves range from two to sixteen degrees. Dump tracks are very irregular, having curves as great as forty degrees. These tracks are moved as dumping progresses. The work of transporting the ore from the benches to the various assembly yards, and waste to adjacent gulches, was being done by approximately 50 steam locomotives, varying in weight from 84,000 to 156,500 pounds.

Owing to the complexity of trackage, together with certain trolley limitations set by operating conditions, consideration was given to all of the various types of locomotives available for this service. Straight electrics were compared with Diesel, gas-electric, and battery locomotives. The Diesel-electric locomotive indicated the lowest cost of any of the locomotives with self-contained power plants, but was not built in a size large enough for the service at Bingham. Calculations indicated that a 75-ton locomotive, with all the weight on drivers, would be required to haul ten empty cars up the four per cent grade at a speed of ten miles per hour. Accordingly, a 75-ton locomotive, of special design, was purchased, having in addition to the standard pantograph, two side-arm collectors, cable reel, and a 680-amp-hr. storage battery. The total weight of this locomotive with battery was approximately 86 tons. Later a 60-ton Diesel-electric was purchased for trial and these two engines were put in competitive service, tests being conducted for several months. The hauling capacity of the Diesel was reduced in proportion to its weight, but as the engine had a 300-hp. rating at sea level, or about 240 hp. at 7000 ft., with only ten per cent overload capacity, it did not compare favorably with the combination electric, having a rating of 1000 hp. and capable of carrying considerable overload for short periods.

Storage battery operation on the benches worked out very satisfactorily except for slow speed and high cost per kw-hr., compared with trolley operation. A suitable type of overhead was designed for bench work which eliminated the batteries on all but seven of the locomotives. A typical trolley locomotive is shown in Fig. 8, and Table III shows the locomotive specifications.

Suitable substation sites are difficult to obtain on a mining property of this kind and consideration was given to portable stations, the final choice being for two permanent stations of the semi-outdoor type, located within the haulage system. Consideration was given to all suitable types of conversion equipment, *i.e.*, converters, synchronous motor-generator sets, and mercury-arc rectifiers. Rectifiers at this time were not considered sufficiently well developed; motor-generator sets had certain advantages, but overall efficiencies decided the issue in favor of converters. The question of shunt-wound versus compound-wound generators was analyzed and decided in favor of the former, cost, simplicity, and speed requirements being the deciding factors. Automatic versus manual stations were considered from all angles, and as automatic stations have many operating advantages this type of station was built. The functioning of these stations has been practically 100 per cent. The total installed capacity for the haulage system is 8000 kw., divided into eight 1000-kw. units. The converters, together with all low-voltage auxiliaries, are housed in brick buildings, 40 by 60 ft., while the converter transformers and high-tension oil-circuit breakers are outdoors. Ventilating tunnels are installed under the machines and are arranged for either natural or forced draft, the heated air being taken out at the roof by means of ventilators placed over each machine. The four machines in each station tie to a common bus, from which are taken eight feeders. These feeders are each a million circular mils in size and are carried around the property on the poles supporting the trolley. The feeder system is so sectionalized that six locomotives are fed from two sources over two separate feeders. Sectionalizing switches are provided at the ends of each bench, as trouble usually occurs at these points. Transfer from one feeder to another can be made very quickly.

TABLE III

LOCOMOTIVE DATA

Dimensions	
Length (inside knuckles)	37 ft. 1 in.
Wheel base, total	25 ft. 2 in.
Wheel base, rigid	8 ft. 0 in.
Height over collector, locked down	17 ft. 0 in.
Diameter of wheels	46 in.
Track gauge	4 ft. 8½ in.
Weights	
Total	170,000 lb.
Per driving axle	42,500 lb.
Electric equipment	45,000 lb.
Air brakes	8,000 lb.
Mechanical parts	117,000 lb.
Traction Motors	
Number and type	4HM-818
Rated voltage	750 d-c.
Method of drive	Single solid gear
Gear ratio	85/18 = 4.72
Ventilation	Natural
Locomotive Ratings	
120 deg. C. Rise by Resistance	One Hr.—Unblown
Tractive effort	35,000 lb.
Coefficient of adhesion	20.6%
Speed	10.4 mi. per hr.
Horsepower	970
Amperes (motors only)	1120
Tractive effort at 25% coefficient adhesion	42,500
Maximum safe speed	30 mi. per hr.
Nomenclature	B+B—170/170-4HM-818-A-750-V.
Control	3-speed Type M
Current collector	Pantograph, also electric cable reel with 2,000 ft. single-conductor cable.

As referred to previously, the complexity of the haulage system, together with certain operation limitations, made the design of an adequate trolley system difficult. Because of the necessity of ditching and spreading operations, all trolley supports had to be placed on the bank side of the track. This condition made necessary curve construction as shown in Fig. 9. Here the pull-over backbone is carried on the end of an extra long bracket arm, trolley and backbone are both strung at reduced tension, and push guys are used on all the poles. The dump tracks are all built on fills, varying in height from 100 to 250 ft. These fills will settle approximately ten per cent. In order to keep proper trolley height the poles are made a part of the track structure, as shown in Fig. 10. Both wood and steel poles are used in this construction. The benches presented the most difficult problem, as the bench track is moved at least once each month. As there was a 5-kv. shovel line on the bench for supplying power to the shovels, it was not considered feasible to have another set of structures to carry trolley, because of the difficulty in moving. At the same time the idea of having a 5-kv. shovel line and a 750-volt trolley on the same structure did not appeal to the mine operators. Accordingly, a pipe structure, having a concrete base, was designed to carry the trolley, and it served its purpose very well, but eventually moving the structure where the benches were narrow became a complicated matter and this scheme was abandoned. The original shovel towers were not suitable for carrying a trolley, as the three conductors were in a horizontal plane in order to have maximum ground clearance with minimum tower height. A new type of tower was designed to carry the 5-kv. feeder on one side of the tower, using triangular spacing, while the trolley was carried on the other side. This tower simplified the moving problem and has given excellent service from an electrical standpoint, at present several hundred being in use. This construction is shown in Fig. 12. All trolley construction is direct suspension, except the Bingham yard, which is catenary on steel structures, spaced 200 ft.

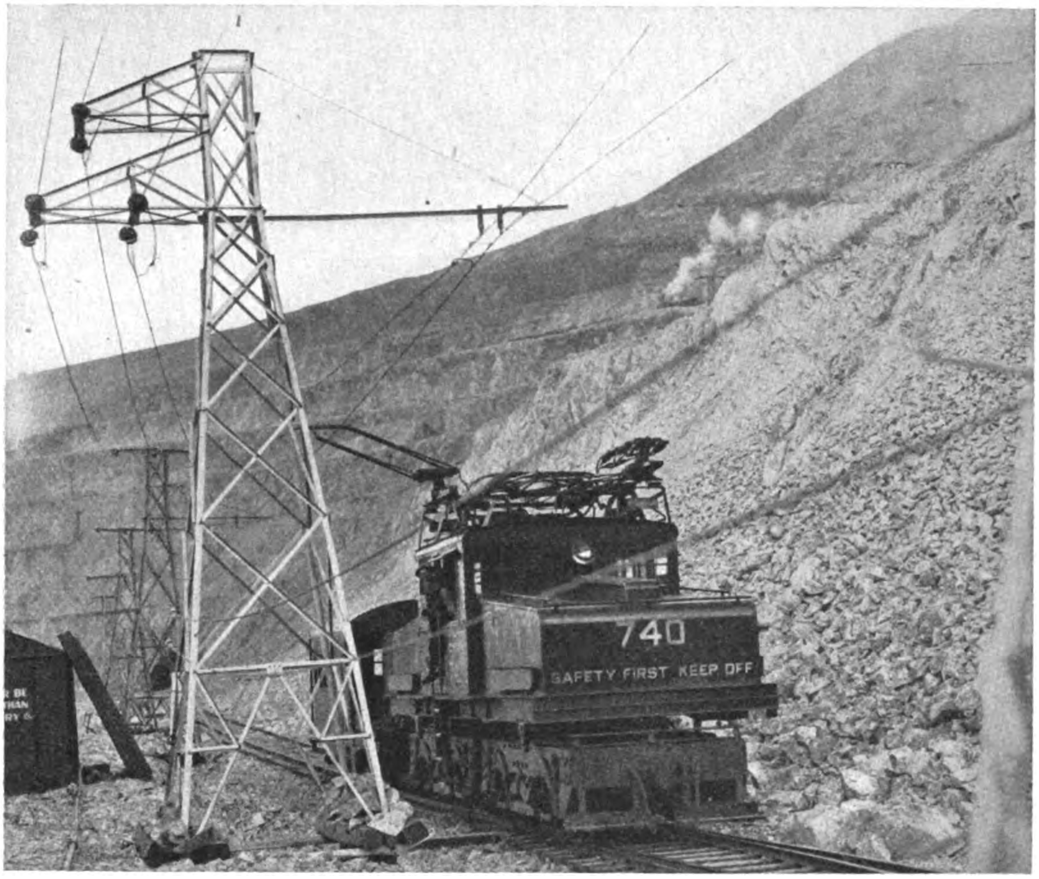

Fig. 12. New Type Composite Tower

Operating economies due to the electrification of the haulage system are not available at this time. The expected advantage may, however, be summarized as follows: elimination of fireman, watchman, and part of engine house crew; abandonment of present coaling and watering facilities; higher speeds and greater hauling capacity, together with customary power saving; and last, but not least, better visibility due to the absence of smoke, which makes the operating conditions safer and better.

Power is furnished by the Utah Power & Light Company, received at Magna Central Station at 120,000 volts and stepped down to 44,000 volts. This station has an installed capacity of 62,000 kv-a., divided into three transformer banks, two 25,000-kv-a. banks supplying the concentrating plants, and one 12,000-kv-a. bank supplying the mine. All 120,000-volt equipment is installed outdoors, while the 44-kv. oil circuit breakers, control board, and measuring equipment are indoors. Fig. 13 shows a view of the control room. A two-circuit steel tower line extends between the Central Station and Bingham, a distance of 14 miles. These steel towers were originally single circuit, arranged for pin insulators; however, when an extension was designed wooden arms were used and disk insulators replaced those of the pin type. Fig. 14 shows a remodeled tower. The two lines to Bingham terminate at a switchrack at the Power Company's station at Bingham, where emergency service is provided in case of line failure. The switchrack is so arranged that lines can operate singly, in parallel, or either or both can be supplied by the Power Company. After leaving the switchrack, the lines divide, going to the two substations which contain duplicate equipments.

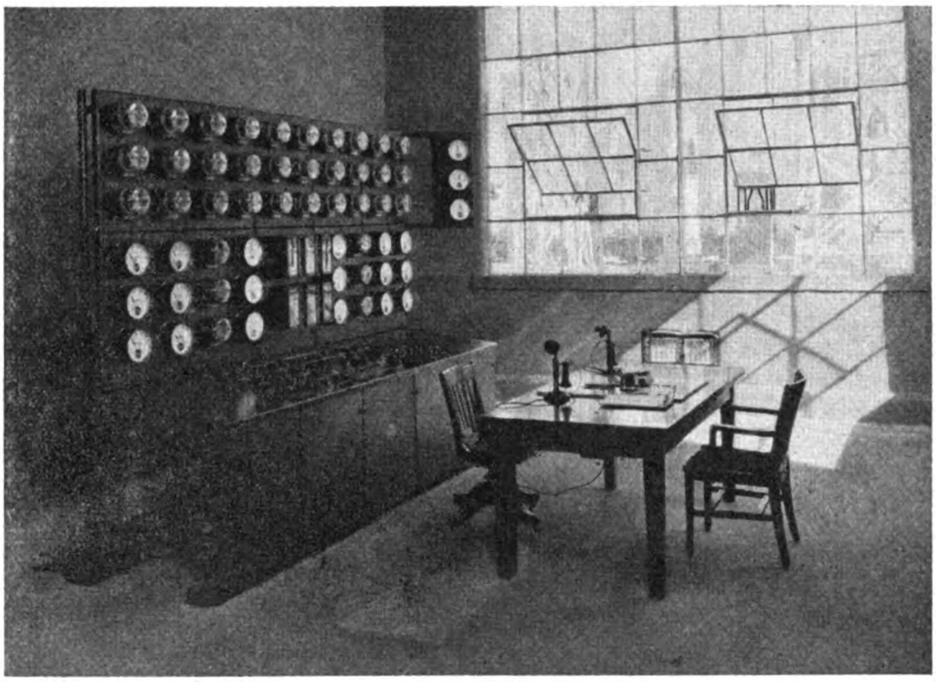

Fig. 13. Control Room

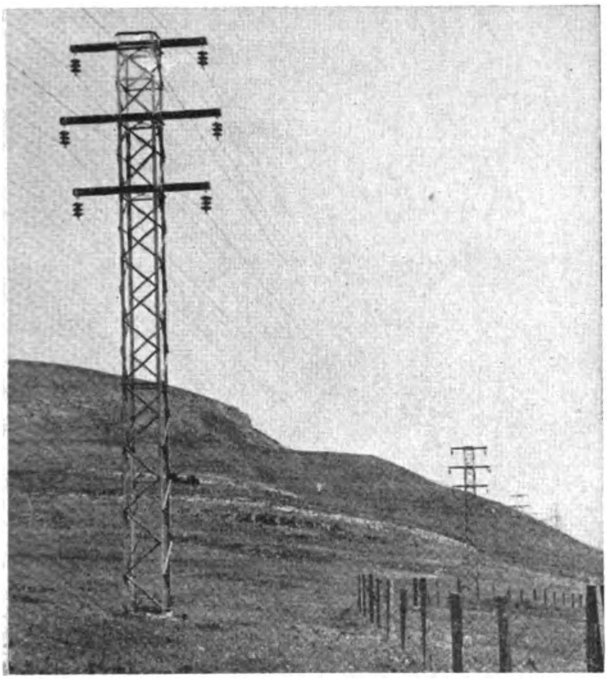

Fig. 14. Remodeled Transmission Tower

Drilling is done with reciprocating, 3½-in. piston air drills mounted on tripods. The air pressure at the drills is about 80 lb. This air is furnished by three 4000-cu. ft. compressors, direct driven by 750-hp., 164-r.p.m. synchronous motors.

The magnitude of operations may be more easily visualized by consulting the following statistics, representative of one year's operation:

Tons of ore loaded	16,556,070
Tons of waste loaded	14,400,170
Total tons of material loaded	30,956,240
Tons of ore hauled by electric locomotives	16,031,728
Tons of waste hauled by electric locomotives	5,465,939
Total tons hauled by electric locomotives	21,497,664
Total kw-hr. used by electric shovels	6,190,136
Total kw-hr. used by electric locomotives	7,536,604

The Development of Modern X-ray Generating Apparatus

PART I

By DR. W. D. COOLIDGE

Associate Director Research Laboratory, General Electric Company

This article the author delivered as the "Caldwell Lecture" before the American Röntgen Ray Society at West Baden Springs on September 24th. Because of its length, we are omitting the salutatory remarks and reporting it in two parts. The second part, which will appear in our December issue, will describe the high-voltage generating apparatus, protection from shock, and timing equipment.
—EDITOR

THE early x-ray tube of Röntgen (Fig. 1), the Crookes tube, was greatly improved by Campbell-Swinton through the introduction of a platinum target; and by Jackson, who turned to account a former discovery of Crookes and used a concave cathode (Fig. 2).

A later step of great importance was the addition of a device for regulating the vacuum of the tube.

For medical diagnostic work, the thin metal target was soon replaced by a heavy mass of metal consisting essentially of two parts, a refractory metal face to take the cathode-ray impact and a heavy backplate consisting of some good heat-conducting metal which would serve to lead away and temporarily store the heat liberated at the focal spot.

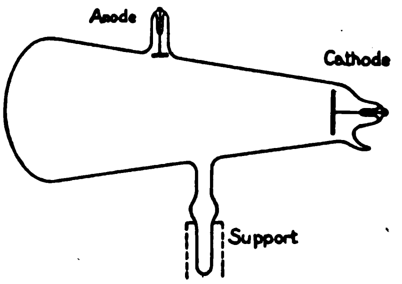

Fig. 1. Early Type of X-ray Tube by Röntgen

Platinum and copper came into very general use for the refractory metal face and backplate, respectively. The platinum facing was made very thin, about 1/1000-in. thick, and was attached to a disk of nickel which, in turn, was soldered to the large mass of copper. The tube had a very definite energy limitation; and if this were exceeded, even for an instant, the thin facing of platinum was ruined at the focal spot and the tube had outlived its usefulness.

Development of Ductile Tungsten

In 1905 some developmental incandescent lamp work was started in our laboratory, which led us later into the x-ray tube field. This work began with an investigation of the mechanical properties of metallic tungsten, and resulted first in the production of this element in a ductile form, and finally in its application for various purposes—among others its use for both electrodes of the x-ray tube.

Up to the time when this work was begun, tungsten had always been a brittle metal—as brittle as glass—and not workable. As a result of laboratory efforts extending over several years and involving many men, it became possible to produce metallic tungsten in a form in which it has the strength of steel.

The process which we developed for producing ductile tungsten is unique in this respect, among others, that it does not involve the melting of the metal in a crucible. This has never been feasible for the reason that there is no suitable material from which the crucible can be made. The fire clays which have been used for crucibles all vaporize at temperatures far below the melting temperature of tungsten.

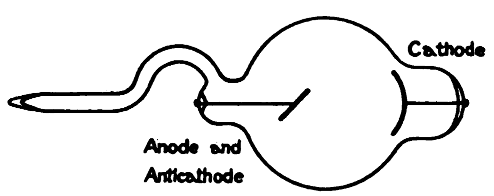

Fig. 2. Jackson's First Tube Employing Focussed Cathode Rays

The process starts with wolframite (an ore consisting of iron, manganese, tungsten, and oxygen) from which the yellow oxide of tungsten is extracted and then highly purified.

This yellow oxide is next reduced to metal powder by heating it electrically in a porcelain tube through which a stream of hydrogen gas is passing (Fig. 3). A very careful and exact control of the conditions of the reduction process is necessary, so that the resulting tungsten particles shall have the proper size.

The dry tungsten powder is next formed under heavy pressure into rods (Fig. 4) and these are then heated electrically almost to the melting point in hydrogen (Fig. 5). The resulting ingots are brittle cold, but with care can be mechanically worked when hot (Fig. 6), and as the mechanical working proceeds the individual crystals are elongated into fibres (Fig. 7) and the metal is thereby strengthened. With sufficient working, the resulting material becomes ductile cold.

The Tungsten Target

After the ductile tungsten process had been developed sufficiently for the needs of incandescent lamp manufacture, the next application which we found for it was as the target of the gas-filled x-ray tube, in place of the platinum which had previously been used.

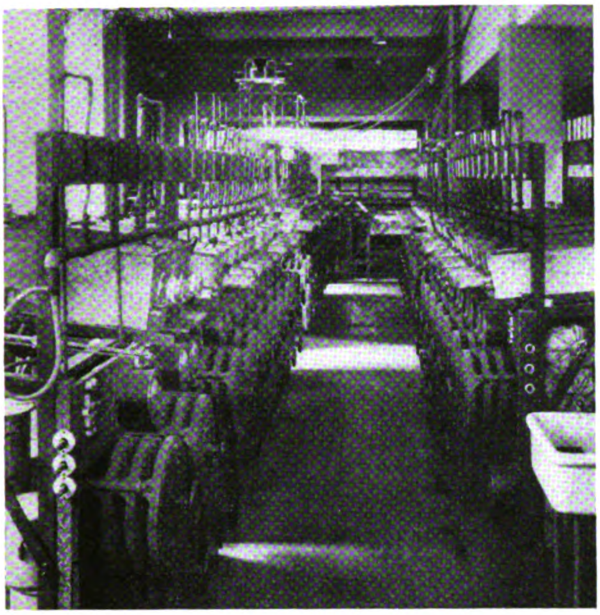

Fig. 3. Battery of Electric Hydrogen-atmosphere Furnaces for Reducing the Yellow Oxide of Tungsten to Metallic Powder

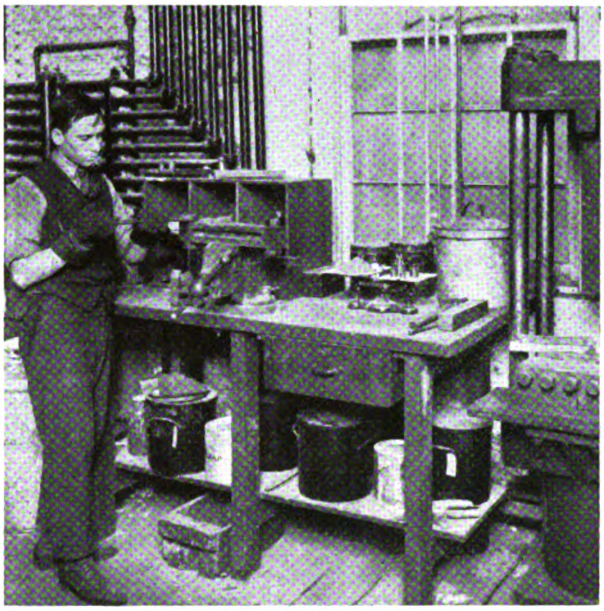

Fig. 4. Compressing the Metallic Tungsten Powder to Rod Form

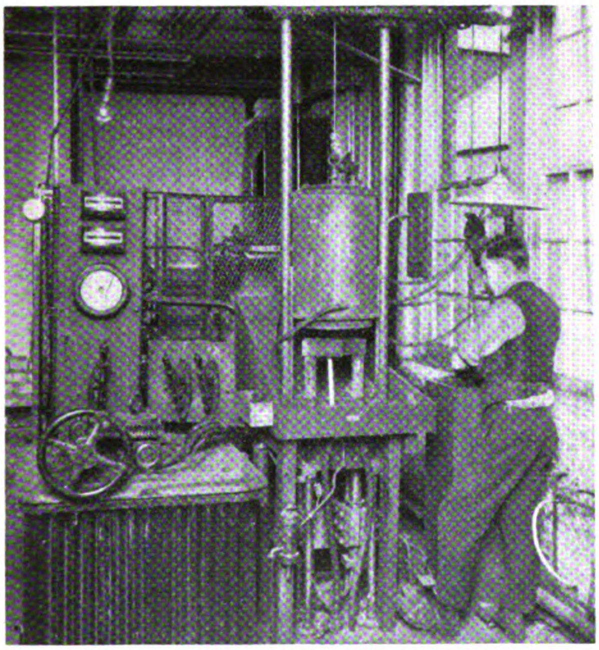

Fig. 5. Sintering Tungsten Rods in Hydrogen Treating Bottle

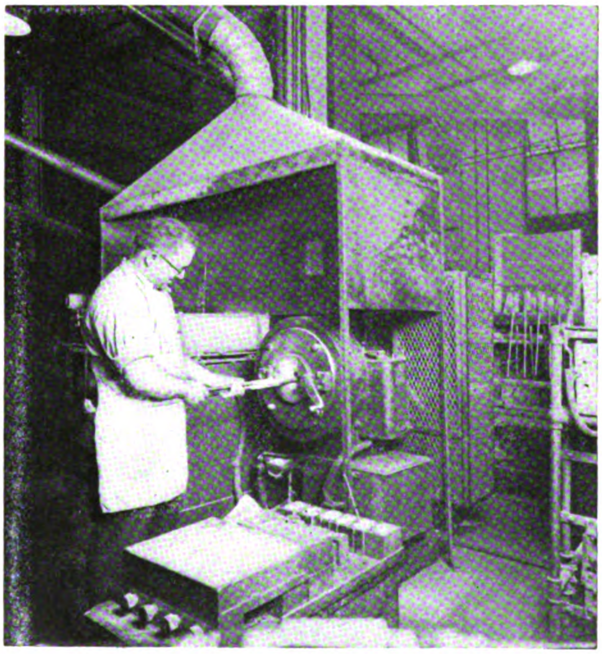

Fig. 6. Hot Swaging the Tungsten Rod

For this application, sheet tungsten was required, and it was found that this could be produced by hot-rolling the original rods or, better, those which had first had a certain amount of hot hammering. From such sheets or strips the small disks required were produced by hot-punching (Fig. 8).

Our next problem—and it caused a delay of many months—was to find a method for bringing a disk of tungsten into good heat-conducting relation with the large block of copper forming the remainder of the target. There was, at that time, no known means for soldering tungsten to copper or to anything else.

It finally developed that copper could be attached directly to tungsten in the following manner: The surface of the tungsten is first carefully freed from oxide. Copper which has been freed of its oxide by treatment with one of the boron compounds is then cast in a vacuum onto the tungsten. Under these conditions, the copper wets the surface of the tungsten as water wets glass, and the result is a union of very high thermal conductivity between the two metals. The practical means employed for carrying out the vacuum-casting operation are as follows (Fig. 9): a cylindrical graphite crucible is made with an inside diameter slightly larger than the desired diameter of the finished target. A removable graphite piece is made to stand in the bottom of the crucible and to serve as a temporary support, at the desired angle, for the tungsten disk. The latter is kept from sliding down the inclined face of its support by three little molybdenum pins which fit in holes in the graphite support. A block of boron-treated copper is then placed in the crucible. The crucible and its contents are then placed, together with others, in an electrically-heated vacuum furnace and the temperature is raised slightly above the melting point of the copper. The temperature must not be too high, as otherwise the strength which has been produced in the tungsten by the mechanical working will be lost and the target will crack badly in use.

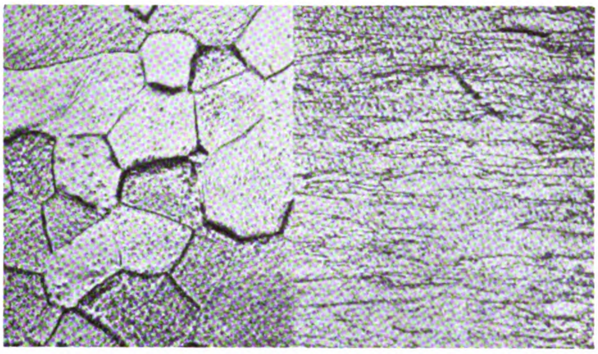

Fig. 7. Photomicrograph of the Crystalline Structure of Tungsten Before Swaging (Left), and the Fibrous Structure Afterward (Right)

The tungsten disk must not be too thin, for, otherwise the copper will melt back of the focal spot and will, by its expansion, cause a bulging out of the tungsten at this point. Upon cooling, the copper will contract, leaving a vacuous space immediately under the tungsten at the focal spot. The target is then ruined, as the good heat conductivity between the tungsten and the copper at the focal spot has been lost. As copper conducts heat better than tungsten, it is, on the other hand, better to have the tungsten disk no thicker than is necessary to avoid the melting of the copper under the focal spot.

The advantages of ductile tungsten over platinum for the target face are its higher melting point, lower vapor pressure, and greater heat conductivity. Its use resulted in better definition in diagnostic work because it made possible the production of much higher x-ray intensities from a given size of focal spot.

Trial targets consisting entirely of tungsten were also made for the gas tube, and, in competition with those of solid platinum, they also looked very attractive as they were capable of radiating much greater amounts of energy from a given surface area.

Before the advent of the hot-cathode tubes, the tungsten target (Fig. 10) had replaced the platinum target almost completely in the high-power radiographic tubes made in this country.

Historical Development of the Hot-cathode Tube

The development work on the copper-backed tungsten target brought with it interesting experiences with gas-filled x-ray tubes that had been built to enable us to test out different constructions and designs of target. Large amounts of energy were passed through these tubes to show which kind of target best withstood abuse. Upon overloading the focal spot, tungsten vapor was produced and this tungsten vapor brought about very rapid changes in gas pressure. These pressure changes are now easily explainable. Dr. Langmuir(1) has found that tungsten vapor unites quantitatively with nitrogen; hence any nitrogen gas was removed as such and deposited as solid nitride on the walls of the tube. Oxygen reacted with hot tungsten to form a solid oxide of tungsten which was also deposited on the bulb. Hydrogen, argon, and helium were tried but it was found that, in time, they also disappear from the space. These gases which do not react with hot tungsten or with tungsten vapor are probably, in part, shot into the glass and, in part, trapped under the tungsten which deposits rapidly on the surface of the bulb when the tube is overloaded.

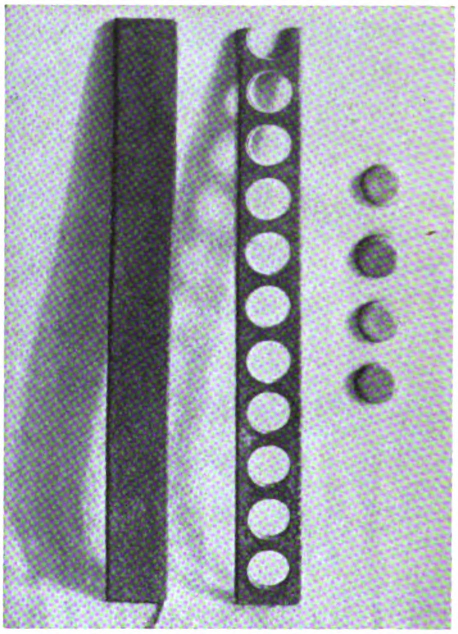

Fig. 8. Steps in the Production of the Tungsten Disks for X-ray Targets

Upon overloading the tubes, the glass around the cathode became very hot and frequently cracked. This was finally prevented by immersing the tubes completely in oil.

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(1) *Jour. Amer. Chem. Soc.*, 35, p. 943 (1915).

Another trouble then made its appearance. The aluminum cathodes melted. To obviate this, a tungsten cathode was tried. This made the tube exceedingly "cranky." One would no sooner get it started than it would refuse to carry current until more gas had been introduced from the regulator.

The extreme instability attendant upon the use of a cold tungsten cathode, in what was otherwise a standard x-ray tube, called attention forcibly to the part played by the gas in the ordinary aluminum cathode. (The tungsten cathodes were relatively very free from gas.)

The need of gas in the aluminum cathode had been well recognized, and, as far back as December 6, 1899, we find a note by Rollins referring to a tube having an aluminum cathode which had been intentionally deprived of its usual hydrogen gas content. He says, "Such a tube could rest until doomsday and not make the faintest spark in the universal gloom."

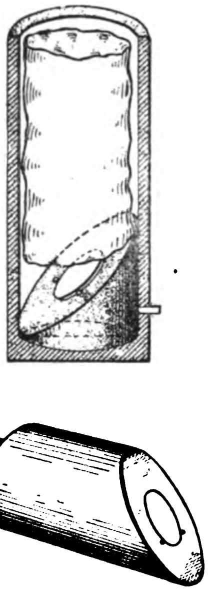

Fig. 9. The Crucible Arrangement for Embedding a Tungsten Disk in a Cast-copper Backing, and the Finished Copper-backed Tungsten Target

In considering the various troubles experienced in the operation of these tubes, one thing was clear, *viz.*, that they all came from the gas in the tube and the positive ion bombardment that took place when that gas was present. It was clearly desirable to get rid of the gas, but it was then imperative to have some other mechanism for getting electrons out of the cathode.

Edison in his work on the incandescent lamp had shown that, in the vacuum of the lamp, current could be made to flow from the hot filament to an anode. Much additional light had been shed on this phenomenon by the work of Richardson (2) and others. Richardson had investigated the law connecting the electron emission with the temperature of the hot body. The values of the currents obtained from hot cathodes by different observers had varied between such wide limits, however, as to suggest that an x-ray tube based upon this principle might be as unstable as the regular gas tube. Furthermore, some investigators had come to the belief that the whole hot-cathode effect was due to gas contained in the cathode itself and that no current would flow from a hot cathode which had been completely freed from gas.

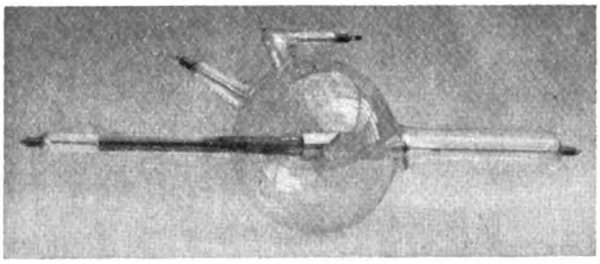

Fig. 10. Cold-cathode Type of Gas Tube Employing Copper-backed Tungsten Target

This was the state of affairs when Langmuir, (3) in our laboratory, took up the study of the electron emission from hot tungsten filaments. He found that the electron emission not only persisted in high vacua, but was favored by getting rid of the last traces of gas in the filament and the other parts of the tube. In this way, he was able to realize conditions which were stable and reproducible.

The same method was tried with the x-ray tube, and we found that here also, even with the much higher voltages and the much larger masses of metal, we were able to get and to maintain vacua in which the phenomena were stable and reproducible. (4)

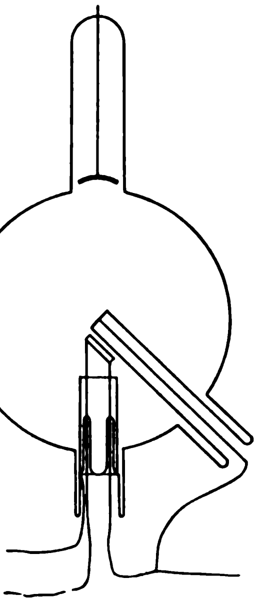

Fig. 11. Early Type of Hot-cathode X-ray Tube by Lilienfeld

The idea of using a hot cathode in an x-ray tube was not new, but the principle had never been successfully applied in a vacuum so good that positive ions did not play either an essential or a harmful role.

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(2) *Proc. Camb. Phil. Soc.*, XI, 286 (1902).

(3) *Proc. Roy. Soc.*, LXXI, pp. 415-418 (1903).

(4) *Phys. Rev.* N. S. Vol. II, No. 6, pp. 409-430, Dec., 1913.

The hot-cathode tube of Wehnelt and Trenkle(5) employed a lime-coated hot cathode as a main electrode, but the vacuum employed was too poor to permit of operation with more than about 1000 volts, as otherwise the positive ion bombardment removed the electron-emitting lime coating from the cathode.

In the early hot-cathode tube of Lilienfeld(6) the main electrodes were exactly the same as in the ordinary gas tube (Fig. 11). By means of current flowing between a pair of auxiliary electrodes, the cathode of which was heated, the gas content of the tube was ionized, and, by varying the discharge current passing between the auxiliary electrodes, the conductivity of the tube could be controlled. The tube operated with a somewhat lower gas pressure than that of the ordinary gas tube. It was still a gas tube, however, and could not be operated if the pressure became too low.

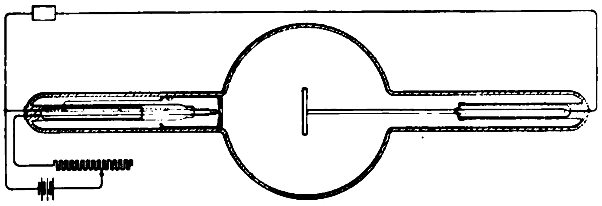

Fig. 12. Diagram of Early Type of Hot-cathode X-ray Tube with Spiral, Tungsten-filament Cathode and Circular, Tungsten-disk Anode, Together with the High-voltage and Filament-heating Circuits

In the first of our tubes, the cathode consisted of a spiral tungsten filament mounted behind a centrally perforated tungsten or molybdenum focussing disk, both filament and disk being set in the cathode side-arm, and the anode consisted of a circular tungsten disk attached to the end of a tungsten support-rod (Fig. 12).

From the earliest form, the design changed, before the tube went on the market, to essentially that of the present "Universal" type (Fig. 13).

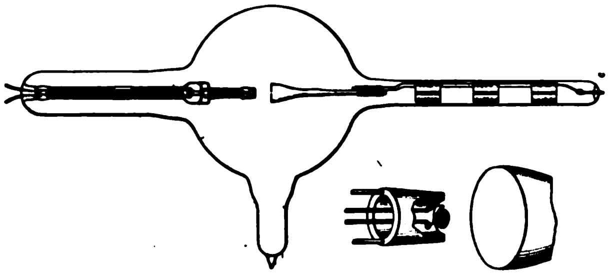

Fig. 13. The Principal Features of the Present-day "Universal" Type of Hot-cathode Tube Developed from the Form Shown in Fig. 12

Experience has shown that the main advantages of the hot-cathode tube over the gas tube are the following:

Flexibility.

Stability, permitting more accurate reproducibility of results.

It can be made much smaller.

It can be operated directly from a transformer, making possible a very simple type of outfit.

Long life.

Heat Removal from Focal Spot

There are only two ways in which appreciable heat removal from the focal area can take place, by direct radiation from the focal spot and by conduction away from the focal spot to other parts of the target from which it can later escape in various ways. The limiting case is that in which the entire focal area is brought to the melting point (if one attempts to go higher than this, the appreciable vaporization of the tungsten leads to great instability in the discharge). With the focal spot at the melting point, the direct radiation amounts to only 3.6 watts per square millimeter. In a tube, then, operating, for example, at 100 ma. and 85 kv. (peak) and having a focal area of 17 square mm. only about 60 watts, or one per cent of the total energy input, would be radiated directly from the focal spot. The large bulk of the energy must then be conducted away from the focal area through the adjacent metal.

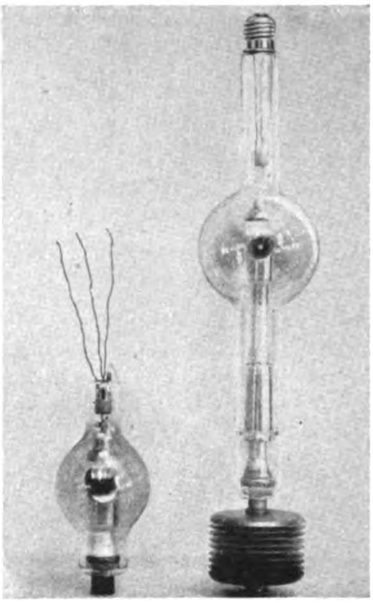

Fig. 14. Oil-cooled and Air-cooled Types of X-ray Tubes

The superiority of a copper-backed target to one of solid tungsten for diagnostic work is due to the fact that copper has much greater heat conductivity than tungsten.

Having got the heat away from the immediate neighborhood of the focal spot, there are various ways of removing it from the head of the target.

In tubes having solid tungsten targets, the major portion is removed by radiation from the body and stem of the target.

In copper-backed tungsten targets, the heat flows through the large copper stem to the radiator outside.

Heat removal may, in general, be further expedited by the use of water. This seems especially desirable in the case of high-power therapy tubes.

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(5) A. Wehnelt and W. Trenkle, *Sitzungsber, d. Phys.* Medic. Soc. in Erlangen, **37**, 312-315 (1905).

(6) J. E. Lilienfeld and W. J. Rosenthal, *Fortschritte auf dem Gebiete der Röntgenstrehlen*, **18**, 256-263 (1912).

Where the tube is operated in oil, the length of the anode stem may be greatly reduced from that required for operation in air and, in this way, heat removal may be facilitated (Fig. 14).

The neck of the bottle in the cooling process in the diagnostic tube is the resistance to heat flow of the metal in the immediate neighborhood of the focal spot.

There are two methods which can be used to minimize the effect of this limitation.

The first consists in changing from single-phase to multi-phase current excitation or, better still, to direct-current at constant potential. The main advantage derived from this method is due to the fact that it does not involve the high peak values of current required to give the same milliamperage on single-phase current. It is these peak values which set the limit in the latter case. The only trouble with this method is that, except in those rare cases where multiphase current is already available in the medical x-ray laboratory, it involves a very considerable increase in the cost of equipment.

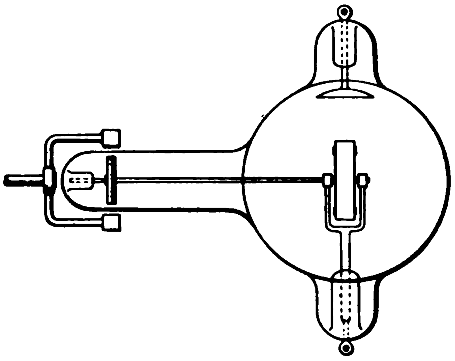

Fig. 15. X-ray Tube with Rotating Target

The second method consists in the use of a lateral movement of the target face with respect to the cathode rays. This method was advocated by Dr. Elihu Thomson in a patent applied for in 1914 in which he proposed to rotate the target by the aid of an electric motor (Fig. 15). The writer(7) has tried this method (Fig. 16), and a commercial tube of this type has been described by Bouwers.(8) The same result has been accomplished by the writer by rotating the entire tube (Fig. 17), while holding the cathode-ray stream stationary in space and bent away from the axis of the tube by means of either a solenoid or a small magnet. Rotation of the entire tube has the advantage over rotation of the anode only in that it does away with the lubricating difficulties attendant upon the use of internal bearings. It also makes easier the removal of heat from the anode by permitting the use of the ordinary solid copper anode stem leading out to a radiator, and even facilitates the action of the latter by rotating it in the air.

By rotation of either tube or target, the allowable energy input per unit area of focal spot can be increased several fold. The future of such a system simply awaits the answer to the question as to whether the gain justifies the complications and limitations involved.

Focal Spot Shape and Size

In tubes having a target angle of 45 deg., the focal spot is elliptical, the longer dimension being about 40 per cent greater than the shorter one. When viewed in the direction of the normal to the target face, the focal spot is seen in its true elliptical shape; in the direction of the so-called "central ray," as a circle; and, in the direction of glancing incidence, as a line.

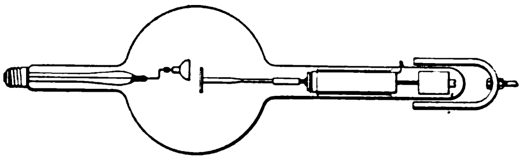

Fig. 16. A Variation of the Type of Tube Shown in Fig. 15

The significance of this change in apparent shape with direction was recognized by Rollins who, in 1897, published a note on "Why the Definition of a Reflecting Focus X-light Tube is Better in One Plane Than Another," and said: "In practical work we should be careful to place the tube in such relation to the patient as to see the oval figure at an angle to reduce its length."

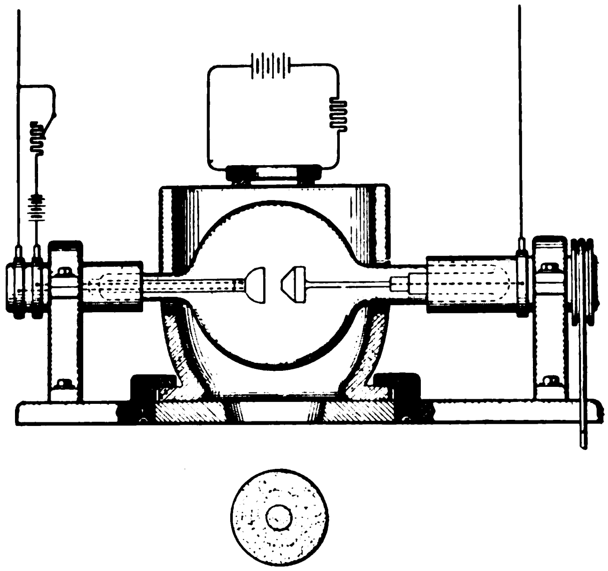

Fig. 17. Rotating X-ray Tube

The fact that the focal spot appears different in different directions leads unavoidably to a certain astigmatism in the radiograph, and this effect increases with ellipticity. If, however, the user will limit himself to a sufficiently narrow cone of rays, taken in the right direction, he can gain considerably by using an elliptical focal spot. The gain consists in an increase in the x-ray intensity per unit of apparent focal area. There is a limit to the ellipticity which can be helpfully employed, for, if it is too great, the rays will have to be taken off at almost glancing incidence, and x-ray intensity falls off rapidly as one approaches close to glancing incidence, especially so if any considerable roughening of the focal area has taken place.

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(7) *Am. Jour. of Roentgenology*, pp. 884-885 (1915).

(8) *Verh. d. Deutschen Roent. Ges.* XX, pp. 103-108 (1929).

In the line-focus tube as made by the Philips Company[9] the ratio of the length to breadth is about three or four to one.

Regardless of the shape of focal spot, for best diagnostic results the size of focal spot should always be as small as can be used safely with the load.

This can be accomplished crudely by having a number of tubes with a variety of focal spot sizes.

The "Dofok" tube, with its two filaments, gives a choice of two different focal spot sizes in the one tube, and is therefore a step in this direction.

The method which would accomplish the result most fully would be that, suggested by Dr. Langmuir,[10] in which the focal spot may be given at will any desired size, the adjustment being obtained instantly by varying the potential of the focussing member of the cathode with respect to the electron-emitting portion. The only objection to thus giving the operator easy control of focal spot size lies in the fact that it complicates matters for him, forcing him to guard constantly against overloading the focal spot.

It would be more nearly ideal if the focal spot size could be *automatically* adjusted to the load. Two methods of automatically adjusting focal spot size to *milliamperage* have been suggested, one by Franke[11] and the other by Kearsley.[12] It would be still more nearly ideal if the adjustment could be to *watts* instead of milliamperage. To be perfect, however, the automatic adjustment for watts should take into account the time factor also, for the shorter the time the smaller the focal spot which can be used for a given wattage. By further complication, this result also could be accomplished.

The desirability of simplicity in technique may lead one away from the ideal condition, however, and experience alone will show just how far it is desirable to go in this matter.

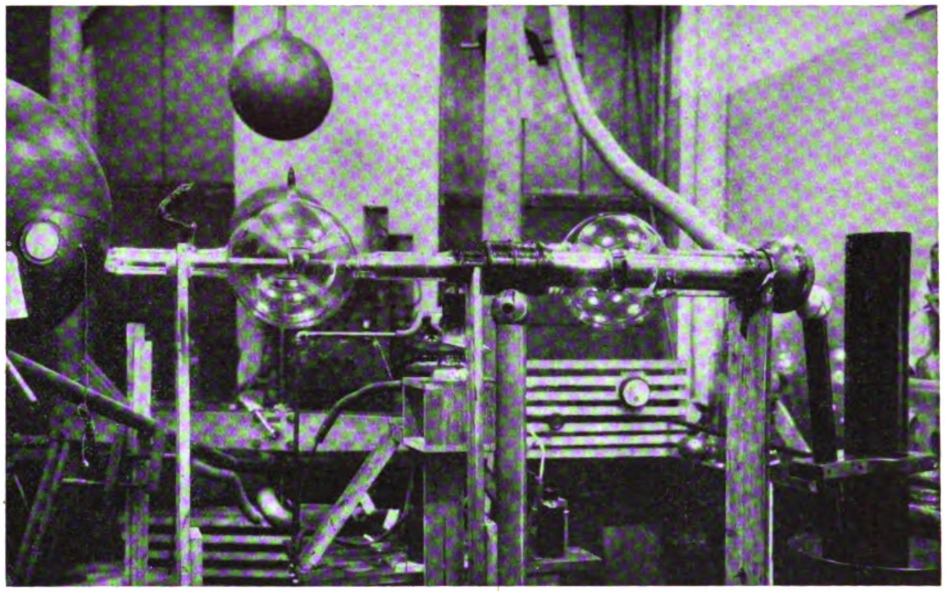

Fig. 18. A 500,000-volt X-ray Tube Built in Two Sections

Tubes for Very High-voltage X-ray Therapy

For this purpose, use can be made of cathode-ray tube development[13] in which it has been shown that tubes can be built for very high voltages by the use of a cascade system. By this method there appears to be no limit to the voltage which can be used.

A two-section x-ray tube of this type has been made to operate very satisfactorily on the pump at 3 ma. and 500,000 volts (Fig. 18). The target is placed, not in the center of the bulb, but inside of the copper shield and near the outer end of the anode arm. In this way most of the reflected electrons are kept from returning to the bulb of the second section and getting into the anode arm. With this tube the x-rays are taken out sideways through a hole in the copper shield and through the glass of the anode arm.

For trial therapy, a three-section tube is being developed for 900,000 volts, to be operated with the anode grounded. In this case the anode will be made thin and the x-rays will be taken out through it, and through the cooling water, in the direction of the axis of the tube.

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[9] Dr. Otto Goetze, U. S. Pat. No. 1590971.

[10] U. S. Pat. No. 1251388.

[11] *Brit. J. Radiol.*, *23*, 134-139 (1927).

[12] *Am. Jour. of Roent. & Rad. Therapy*, XXIII, pp. 170-172 (1930).

[13] W. D. Coolidge, *Amer. Jour. Roent.*, XIX, No. 4, pp. 313-321, (1928)

(*To be continued*)

The Measurement of Corona Losses

By **F. M. DENTON**, F.C.G.I., *Fellow* A.I.E.E.,

Professor of Electrical Engineering at the University of New Mexico

IN a paper read at the Convention of the A.I.E.E. held at Columbia, Mo., in March, 1930, the University of New Mexico Branch described novel methods of measuring corona losses in a-c. transmission lines.

In addition to measurements such as usually are made on the low-voltage side of the transformer supplying power to the line, the following measurements were made on the high-voltage line itself:

(*a*). One line being grounded, current readings A_1, A_2, and A_3 were taken (see Fig. 1).

(*b*). A stroboscopic disk D driven by a synchronous motor and having a radial black mark upon it, was illumined by two Neon glow lamps, L_1 and L_2 (each taking about a milliampere at 110 volts), the lamp L_1 being shunted across a noninductive resistance R_1 in series with the grounded line, while L_2, in series with a high resistance R_2 was shunted across the high-voltage line.

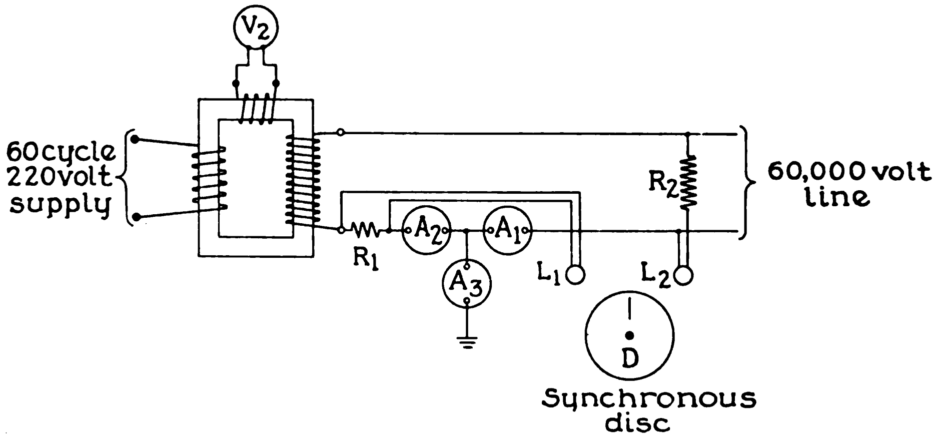

Fig. 1

The ammeter readings A_1, A_2, and A_3 form a triangle (see Fig. 2), showing the phase relation of the currents causing corona loss. This gives a more complete analysis than is obtained by the usual method in which only the line currents are measured.

The angle θ between the two images of the mark as seen on the stroboscopic disk, measures the phase difference between A_2 and V_2. The corona loss is $A_2 \times V_2 \times \cos\theta$.

With wires of small diameter the distortion of the current wave makes necessary a correction of θ but it is probable that with conductors of commercial size that correction will be negligible. The writer hopes that such tests may be made upon commercial lines. The tests hitherto made at the University of New Mexico have been on small wires with about twenty centimeters spacing at a line voltage of 50,000.

The cost of the apparatus is small and the measurements are easily made. Any small d-c. series motor can be turned into a suitable synchronous motor by filing down some of its armature teeth so as to provide slightly salient poles. The Neon glow lamps take only about one-tenth of a watt (one milliampere at about one hundred volts) so that on, say, a 100,000-volt line the power taken in the potential circuit is only 100 watts.

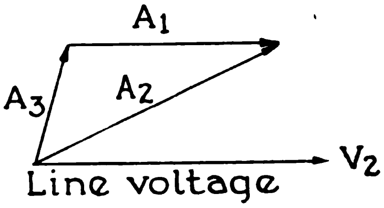

Fig. 2

R_1 is a simple wire or strip rheostat while R_2 is a long strip of blotting paper (or, preferably, blotting card, glazed on one side) soaked with India ink. Such a resistance capable of carrying a milliampere and having about 50 megohms resistance was made by clipping together a number of 8-in. by 4-in. blotting cards, making a length of about five feet. The blotting side of the cards was well soaked in Higgins' drawing ink and dried.

The Application and Performance of Series Capacitors

The Function of the Capacitor—Comparison with Other Regulative Equipment—Applications for Line Regulation—For Division of Load in Loop Circuits—Protection of Equipment—Analysis of Capacitor Installation

By M. I. ALIMANSKY
Capacitor Engineering Department, Pittsfield Works
General Electric Company

COMPENSATION of line voltage drop is desirable for many reasons and a number of devices have been produced to accomplish this. Unfortunately, a device which can neutralize resistance drop is not available, but the drop across a capacitance is exactly opposite to the drop across an inductance when the same current passes through both. And, if the capacitive reactance $X_C = \frac{1}{2\pi f C}$ be made equal to the inductive reactance $X_L = 2\pi f L$ in any series circuit, then the drop from generator to receiver would be due only to resistance.

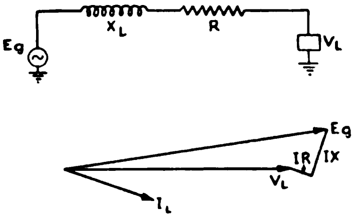

Fig. 1. Schematic and Vector Diagrams of a Power Circuit Containing Resistance and Inductance

For illustration, let us take a circuit (Fig. 1) containing resistance and inductance in series, the sending and receiving voltages being unequal and out of phase; but let us insert a capacitive reactance such that $X_C = X_L$ as shown in Fig.2.

Now, it is obvious that the voltages are much more nearly equal and in phase. Taking representative values, Table I shows the value of the series capacitance in improving regulation. The resistance R has been assumed 0.79 ohms, $X = 1.00$ ohms, $I = 200$ amp. cos θ = 0.8 and $V_L = 2770$ volts.

TABLE I

	V_L	E_g
Without capacitor...........	2770	3020
With capacitor (2.2 ohms)....	2770	2770

SERIES CAPACITOR APPLICATION

For Low-voltage Short-line Regulation

Although series capacitors show great promise of usefulness in the field of long-distance high-voltage transmission, the immediate need of them is to a greater extent on low-voltage existing systems. There are many rural lines and networks which would be benefited by the use of series capacitors.

Several methods can be used to improve the voltage regulation of a transmission system, outlined as follows:

(1). Higher voltage, larger wire, or parallel lines.
(2). Induction regulators.
(3). Synchronous condensers.
(4). Shunt capacitors.
(5). Series capacitors.

Methods 1 and 2 are those most generally used for voltage regulation; but for a typical rural line, 10 mi. long, rated 4 kv., 3 phase, 60 cycles with an equivalent spacing of 33.6 in., 0.75 p-f. and an assumed permissible regulation of 10 per cent it was found that if two cases were compared—one where series capacitors were used with No. 4 wire, and the second no series capacitors and No. 2 wire (both giving approximately equal regulation), a net saving of about six per cent in annual operating cost could be realized by the use of series capacitors. Parallel lines necessarily involve added expenditures in line construction; and higher voltage entails increased transformer or generator cost.

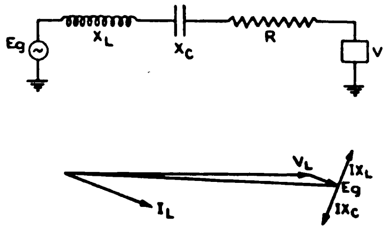

Fig. 2. Diagrams of a Power Circuit in which Reactance is Balanced by Capacitance

On rural lines, the accepted method for voltage regulation is the use of the induction voltage regulator. Undoubtedly there are numbers of cases where the series capacitor is more applicable than the induction voltage regulator from the economic standpoint.

From the standpoint of maintenance, the series capacitor is sturdy, has few moving parts, and requires little attention. Neither the series capacitor nor the regulator decreases line losses in any way, but the internal losses of the capacitor are much less than those of the regulator.

The synchronous condenser with its control equipment is more complicated than the series capacitor. Operation may be manual, requiring an operator, or automatic, requiring periodic inspection. The losses of a synchronous condenser vary from about 1 ½ per cent of its rating on the very large sizes to about 5 per cent of its rating on the smaller sizes, while the series capacitor losses amount to about 0.25 per cent of its rating. However, by power-factor correction, the synchronous condenser reduces line losses; but usually the balance is in favor of the series capacitor when the line is short.

Strictly, the synchronous condenser can improve voltage regulation in one way, by changing power-factor. The reactive current drawn by the synchronous condenser through the line inductance causes a voltage change which improves regulation.

The shunt capacitor is similar in its operation to the synchronous condenser. It also improves voltage regulation only by improving power-factor; but the shunt capacitor has the disadvantage of being inflexible, unlike the synchronous condenser. If left on the line at light loads or no load, it will continue to draw leading current through the reactance of line and transformers, which will produce a voltage rise at the distribution points—a condition as disadvantageous as too low a voltage.

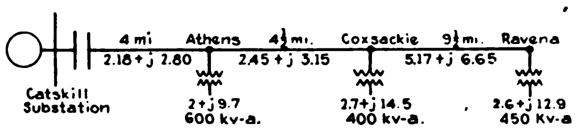

Fig. 3. Actual Transmission-line Diagrams, Showing Values of Voltage and Impedance

In order to give the best operating conditions, a shunt capacitor should be located at each load point in proportion to the load at that point.

A shunt capacitor has very low losses (0.25 per cent); in addition, it decreases line and transformer losses. Thus in most cases, their use results in a net decrease in losses.

Recently, there was installed at the Catskill (N. Y.) substation of the Central Hudson Gas & Electric Corporation, a bank of three series capacitors for the purpose of improving voltage regulation on an 18-mi. 13,200-volt 3-phase line. The one-line diagram of this circuit is shown in Fig. 3.

The problem was to improve voltage regulation at the three load points, Athens, Coxsackie and Ravena. When the analysis was made it was found after considering the several possible methods of improving voltage regulation that, except for voltage regulators situated at each load point, a single bank of series capacitors at Catskill offered the best voltage regulation over the entire line. From the economic point of view, series capacitors showed the lowest operating costs. Taking the series capacitors cost as 100 per cent, the comparative figures for the other methods were as follows:

Induction regulators	166 per cent
Shunt capacitors	243 " "
Synchronous condensers	166 " "

Three single-phase units, each rated 90 kv-a., 940 volts, 96 amp., 60 cycles, were installed. Each unit consisted of eighteen small 5-kv-a. capacitors mounted on a rack, as shown in Fig. 4. The cases of the eighteen small units were connected to the rack and the rack, in turn, was connected to the line terminal. Thus the entire rack is at line potential and can easily be insulated from ground by the small porcelain insulators shown in Fig. 4. The rack was placed in an elliptical tank (Fig. 5) and the unit equipped with protective apparatus.

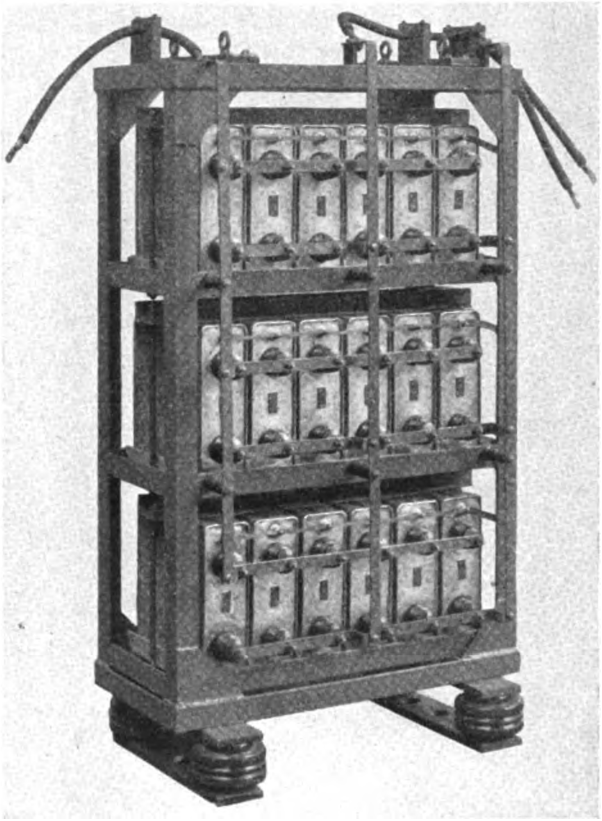

Fig. 4. Interior Capacitor Rack for a 90-kv-a. Series Capacitor Insulated for 13,200 Volts to Tank

This installation will be closely observed by transmission engineers and public utility operators. It will demonstrate the effect of series capacitors on a medium-voltage line.

For High-voltage Long-line Application

Advantageous as are series capacitors on a short line for voltage regulation, they show as much, if not more, promise of usefulness in the field of high-voltage long-distance transmission. There they are not only effective for line regulation, but they serve to increase the power limit.

Transmission engineers have long known that the inductive reactance of a long system plays a very important role in the stability of the system. Any device which could be made to neutralize or compensate this reactance would at the same time increase stability. Such a device would be very desirable from an economic standpoint, also, as in long lines (200 miles or more) the economical load approaches very closely the maximum power which can be transmitted with stable operation. With any given line, it may never be practical to actually transmit this amount of power; but it is well to have the steady-state power limit as high as possible, as the greater this figure, the greater will be the ability of the system to withstand shocks.

The maximum power transmittible over a line is given by the following expression:

$$P_{R\,(\text{max.})} = \frac{E_R}{1000}\left[\frac{E_S}{X_o} + \frac{R\,E_R}{X_o^2}\right]$$

where

$P_{R\,(\text{max.})}$ = maximum power in kilowatts
E_R = voltage at receiving end
E_S = voltage at sending end
R = resistance of line
X_o = reactance of line.

It can be seen therefore that the greater the reactance the less the maximum power.

Here

$$X_o = \omega L \text{ and } L = K \log_e \frac{D}{r}$$

thus

$$X_o = \omega\, k \log_e \frac{D}{r}$$

where

$\omega = 2\pi \times$ frequency of system
L = inductance (henries)
D = spacing between conductors
r = radius of conductors.

The reactance then can be decreased by using smaller spacing. This factor, however, is governed by the operating voltage and corona; it is usually impossible to select the spacing from a consideration of the reactance alone.

From basic electrical theory, it has been known for some time that reactance can be neutralized by series capacitance, and in this way the steady-state stability limit might be increased, but no practical use has been made, as yet, of this principle.

This question of increased power limit has been previously treated in this magazine.(1) A typical system (Fig. 6) was considered, consisting of a hydroelectric generating station transmitting power over a 250-mile line to a load center, where also a steam station, large in generating capacity, as compared to the hydrostation, was located. The installation at the hydrostation was assumed 120,000 kv-a., consisting of four identical generators on the same bus. The steam station was assumed so large that it was considered an "infinite bus." A 60,000-kv-a. synchronous condenser was assumed at the load point.

The series capacitance of such a value as to neutralize all line and transformer reactance was assumed situated at the middle of the line, 125 mi. from either end. Six capacitors, each of 10.07 mfd., were assumed.

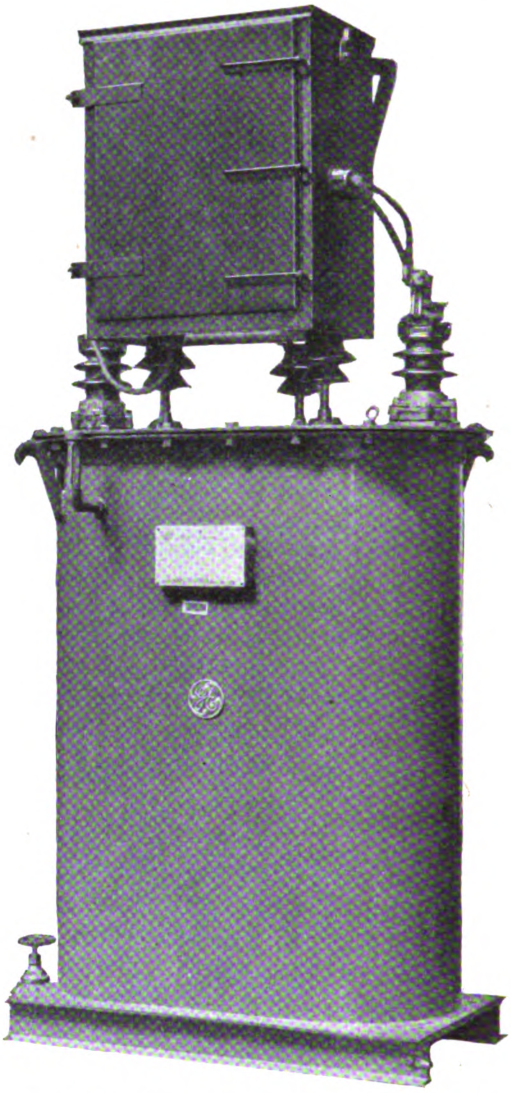

Fig. 5. Completely Assembled 90-kv-a. 940-volt Series Capacitor for 13,200-volt Tranmission Line

The problem was attacked theoretically, assuming an initial load of 50,000 kw. at a power-factor of 96.3 per cent. The maximum power obtained with the line compensated was 113,000 kw., non-compensated, 53,000 kw. These results show that the balance is in favor of series capacitors. By their use, the original load can be increased 126 per cent as against six per cent for non-compensated operation. There seems to be no doubt that in the former case there is much more power available for additional load switching;

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(1)"The Effect of Series Capacitors Upon Steady-state Stability of Power Systems," by E. J. Allen and J. L. Cantwell, GENERAL ELECTRIC REVIEW, May, 1930, pp. 279-282.

and it is found that the field current for the compensated case is 30 per cent greater than for the noncompensated system which will give added stability to the compensated line.

Under normal conditions the system operates with an extremely low overall impedance. Thus, in the event of a fault, there is little reactance to limit short-circuit current. Commercial series capacitors are equipped with short-circuiting mechanisms for protection of the capacitors from over-voltage, which in addition serve to reinsert the reactance in the system to limit short-circuit current.

There is one disadvantage in the compensated system. The voltage at the hydrostation generators is a little higher than normal in order to keep 100 per cent voltage at the load. The additional 6.5 per cent would not be desirable if a load were connected directly to these generators; but this case is exceptional. Usually there is no load directly connected to the hydro-generator bus.

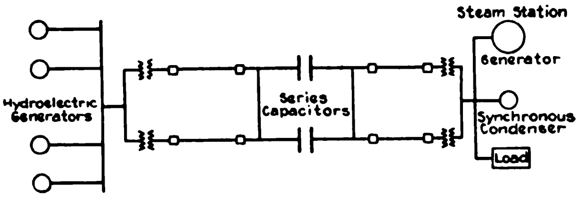

Steam Station
Generator
Hydroelectric Generators
Series Capacitors
Synchronous Condenser
Load

Fig. 6. Diagram Showing Application of Series Capacitor to an Interconnected Power System

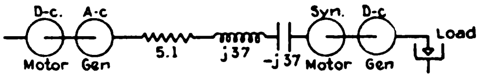

D-c.
A-c
Syn.
D-c
Load
Motor
Gen
5.1
j37
-j37
Motor
Gen

Fig. 7. Diagram of a Miniature Line Used to Determine Effect of Series Capacitors on Power Limit

This study indicates the relative effects of synchronous condensers and series capacitors in maintaining stability for the system considered. The figures must not be taken as representative of all cases, but they show what can be done in one general system.

The question of increased power limit has also been attacked in another manner. Tests have been made on a miniature 500-mile line to determine the effect of series capacitors on power limit. Fig. 7 represents the circuit.

Two similar motor-generator sets were used, each motor being direct-connected to a d-c. generator. The motors were each rated 225 hp., the generators 150 kw. The d-c. units could be used to drive or load the a-c. units. The load was a water box, and driving power was supplied from a 250-volt bus. Commercial 2400-volt 2.34-mfd. capacitors in sufficient number to give 37 ohms capacitive reactance were used to neutralize the 37 ohms of inductive reactance.

The load was slowly applied until the two synchronous machines pulled out of step. Table II gives the results of tests made.

From the results in Table II it appears that the power limit of long lines may be appreciably increased by neutralizing line inductive reactance. Further tests were run with the inductance and capacitance short-circuited, and it was found that the power limit was equal to that of the completely neutralized line.

To Decrease the Magnitude of Sudden Voltage Variations

Frequently, there are cases where a varying load together with a lighting load draw power from the same circuit. This varying load may be drawn by an arc furnace in which the arc is struck and broken very frequently, or by an electric shovel in which the motor makes frequent starts and stops. In both these examples, the load rises from zero to maximum in a very short time. If the combined loads—lighting and power—are fed from a circuit having appreciable reactance, an undesirable flicker may often be produced in the lights due to the regulation of the circuit.

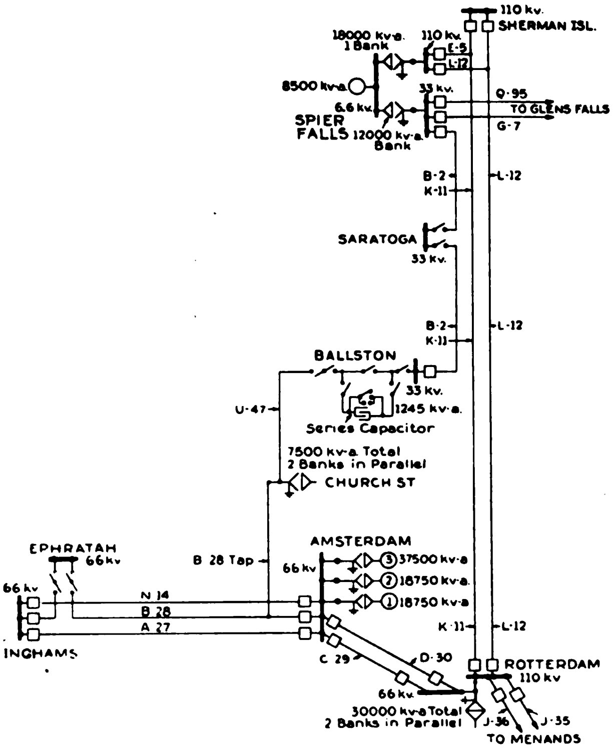

110 kv.
SHERMAN ISL.
18000 kv-a. 1 Bank
110 kv.
E-5
L-12
8500 kv-a
33 kv.
Q-95
6.6 kv.
TO GLENS FALLS
SPIER FALLS
12000 kv-a. Bank
G-7
B-2
K-11
L-12
SARATOGA
33 kv.
B-2
K-11
L-12
BALLSTON
33 kv.
U-47
1245 kv-a.
Series Capacitor
7500 kv-a. Total 2 Banks in Parallel
CHURCH ST
EPHRATAH
66 kv
B 28 Tap
AMSTERDAM
66 kv
③37500 kv-a
②18750 kv-a.
①18750 kv-a
66 kv
N 14
B 28
A 27
K-11
L-12
INGHAMS
C 29
D-30
ROTTERDAM 110 kv
66 kv.
30000 kv-a Total 2 Banks in Parallel
J-36
J-35
TO MENANDS

Fig. 8. Single-line Diagram of Connections of Series Capacitors in the 33-kv. Circuit of the Ballston-Amsterdam Circuit of the New York Power and Light Corporation

TABLE II

System	Generator Excitation amp.	Motor Excitation amp.	Max. Power by Test kw.	Calculated Max. Power kw.	Max. Power in Per Cent of Ultimate
Bus-connected machines..........	3.8	3.8	86	81	100
500 mi. Neutralized line............	3.8	3.8	72	71	83.8
500 mi. Straightaway line (unneutralized).....	3.8	3.8	51	48	59.3

It is virtually impossible to do away with this flicker by means of a voltage regulating device which is partly mechanical in its action. The series capacitor is now proposed as an effective aid, as it is inherently automatic in its action.

For Division of Load in Loop Circuits

The series capacitor has still another important application in the power system, for by its use the load distribution in the various branches of a loop circuit can be controlled. Frequently it is found, when several systems are tied together, that, because of high inductive reactance, some lines in a loop circuit are not carrying their proper share of load. Such a situation can be remedied by means of a series capacitor and the line forced to carry its proper share of load.

An illustration of this application is the series capacitor installation at Ballston (N. Y.), on the lines of the New York Power and Light Corporation. This installation was for the purpose of increasing the load-carrying capacity of the Ballston-Amsterdam 33-kv. circuit which is one side of a loop system between the Spier Falls generating station and Amsterdam, as shown in Fig. 8.

This bank of three series capacitors rated 1245 kv-a. (415 kv-a. each) was put in service in March, 1928. With the compensation of line reactance, the load current was increased from 33 to 67 amp. and the voltage on the distribution buses at Ballston increased very appreciably, also. In this case, the line reactance was 24 ohms. To compensate, 110 mfd. per phase were required. Each 415-kv-a. unit was designed for a full-load current of 132 amp. and 3170 volts at the system frequency, 60 cycles. In the internal assembly of the single-phase unit, 84 capacitors are mounted on a steel rack, one terminal of each capacitor being connected to the terminal boards shown on top. Seventy-eight units are actually used, the remaining six being held as spares in case of failure. Spare units can be substituted for any failures, merely by changing connections on the terminal boards. Fig. 9 shows the complete 3-phase installation at the Ballston substation.

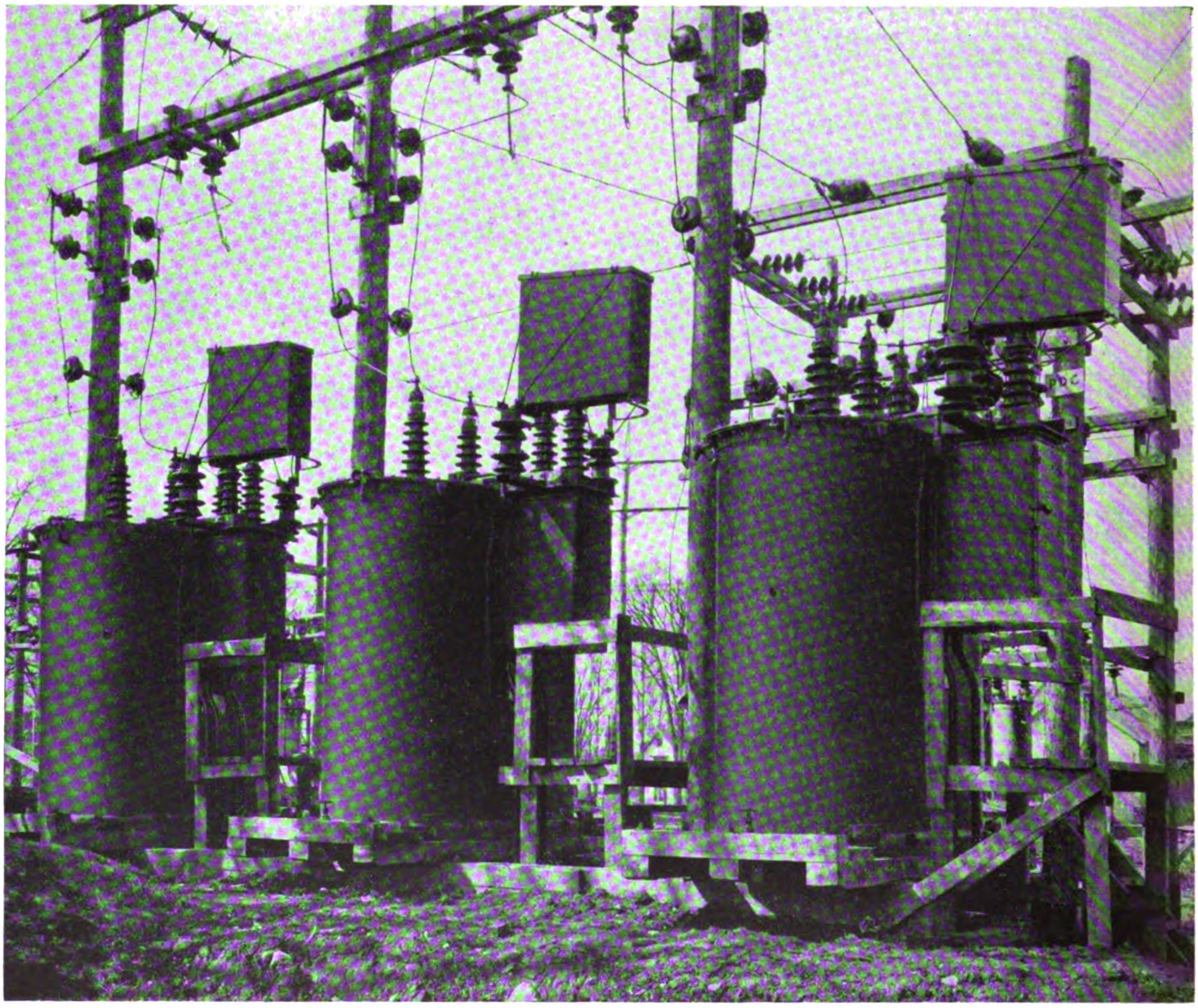


Fig. 9. Three-phase Installation of 415-kv-a. Series Capacitor Units at Ballston Substation of the New York Power and Light Corporation

This installation has been in operation since March 2, 1928 and except for a few interruptions, such as must be expected with any new development, has proved very satisfactory. By its dependable service, it has become a necessary part of this large system.

PROTECTIVE SCHEMES

The series capacitor carries line current. Therefore the drop across it is directly proportional to the line current, and any abnormal increase in this current will cause an abnormally high voltage across the capacitor, at times high enough perhaps to have a deleterious effect upon the dielectric. In order to prevent failure of the dielectric, protective apparatus has been developed which automatically short-circuits the capacitor when the voltage drop rises to 150 per cent or 200 per cent of its normal value.

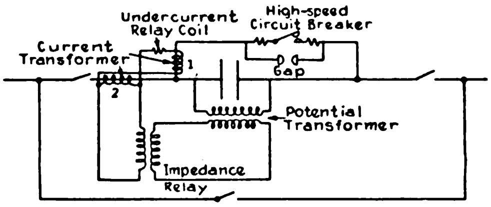


Fig. 10. Elementary Diagram of Series Capacitor with Its High-speed Circuit Breaker Protective Equipment

The abnormal current may be due to a steady overload or a short-circuit on the load side of the capacitor. Should either of these two conditions occur, a sphere gap across the capacitor would spark over, thus causing a breaker to close and to short-circuit the units. In addition to protecting the capacitors, this short-circuiting feature serves to reinsert the line reactance into the system, which, adding to the terminal reactances, serves to reduce the current in case of short-circuit.

The series capacitor, as has been shown, consists of a number of small units in parallel. Should any one of these units fail, the line current would be shunted through this defective unit and the corrective value of the capacitor would be gone. To prevent further trouble arising from any individual failure, the protective apparatus is arranged to short-circuit the capacitor in case of dielectric failure also.

Two protective schemes have been perfected, first, one using a high-speed breaker; second, a low-voltage type using a simple contactor.

High-speed Circuit Breaker

The high-speed circuit breaker protective scheme was developed for the Ballston installation and is readily applicable for any voltage and current. Fig. 10 gives the elementary connection scheme. Upon dielectric failure the voltage across the capacitors would drop at once to a very small value. This would cause an unbalance in an impedance relay which, in turn, would cause the closing of the high-speed circuit breaker. In case of steady overload, if sufficiently great, the gap would sparkover, causing current to flow through transformer *1*. A current relay (not shown) is connected to the transformer secondary which serves to trip the breaker. A short-circuit on the line would cause the breaker to trip out by the action of the sudden increase in current, through current transformer *1* on the tripping circuit connected to its secondary.

Should the circuit breaker close at overvoltage, it would automatically open upon return to normal conditions. This is effected by an undercurrent relay actuated by a current transformer in series with the breaker. A 125-volt d-c. source is necessary for the control devices.

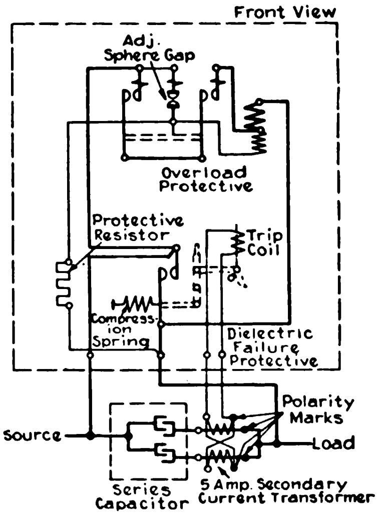


Fig. 11. Diagram of Protective Circuit for a Series Capacitor

Contactor

For an installation on a medium or low-voltage line, especially at a point where 125 volts d-c. is not available, a simpler protective scheme has been developed. Fig. 11 shows a circuit in which the capacitor is protected by a sphere gap. Upon overvoltage, the gap sparks over. The current drawn through the gap flows through the holding and closing coils in series. This closes the two contactors which are in series across the capacitor. After the contactors are closed, they are held in by the holding coil alone. Should the line current drop back to normal, the holding coil will release the contactors, thus replacing the capacitors in the circuit.

It will be noted that the capacitor is divided into two parallel sections. In series with each section is a current transformer. The secondaries of the two transformers are differentially connected to a trip coil. Should a unit fail in any section, the total line current thus tends to flow through the fault, causing a voltage to appear across the current transformers, which act to trip the second contactor.

Both protective schemes accomplish the same results, *viz.*, they protect the capacitors against overvoltage, short-circuiting them in case of dielectric failure, and they reinsert the line reactance into the system in case of short-circuit. The latter function is quite important from the standpoint of the system. Fig. 12 shows the high-speed circuit breaker and control devices. Fig. 13 shows the contactor type of protective equipment.

Conclusions

From the preceding, the following are a few of the conclusions indicated:

(1). Series capacitors, by their inherent property of neutralizing inductive reactance can be used to:

(*a*). Improve voltage regulation on low and medium-voltage lines, such as are used to supply rural communities.

(*b*). Increase power limit or steady-state stability on long-distance high-voltage transmission systems.

(*c*). Control load division in loop-circuits.

(*d*). Eliminate flicker on lighting circuits.

(2). From analyses made, it has been shown that in a number of cases, series capacitors will not only improve conditions, but do so more economically than other types of apparatus.

(3). Protective apparatus for use with series capacitors not only prevents failure of the capacitors during abnormal conditions, but also protects the system in case of dielectric failure or short-circuit.

Although the advantages of using series capacitance have been known for a long time, little was done toward practical application until recently; but now commercial outdoor units have been developed and put in service. One installation has been in operation since March, 1928.

It may be concluded, therefore, that the series capacitor has been developed to the stage whence it is ready for commercial application. It has shown itself to be practical, not only from the engineering viewpoint but also from the economic standpoint. Alternating-current transmission can now be given the same desirable characteristics as direct-current transmission, yet retaining its own inherent advantages.

As an indication of the consideration the series capacitor is receiving in power companies, the following report of the Rural Lines Committee of the Empire State Gas and Electric Association is included. This report, which contains the results of both theoretical studies and practical operation of the series capacitor, was prepared by a Sub-committee on Series Capacitors for Voltage Regulation, composed of Messrs. D. A. Lewis, W. W. Perry, and E. K. Karcher, subcommittee chairman.

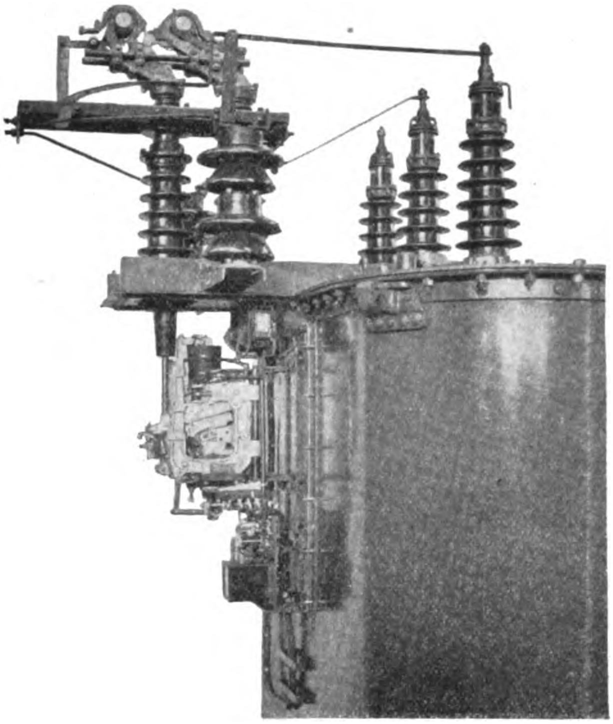


Fig. 12. Protective Sphere-gap Equipment for 415-kv-a. Series Capacitor Used in 33,000-volt Transmission-line Regulation

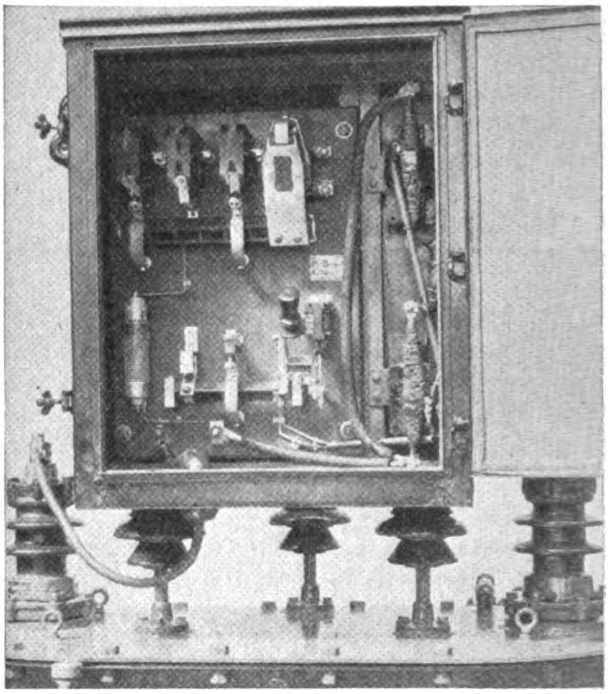


Fig. 13. Protective Contactor Equipment for 90-kv-a. Series Capacitor for a 13,200-volt Line

Report of Sub-committee on Series Capacitors for Voltage Regulation

What is a Series Capacitor?

In construction it is similar to the well-known form of capacitor commonly used to improve the power-factor of large induction motors, being an assembly of capacitor units combined in the sizes and quantities required for any given conditions. The difference lies mainly in the method of connection. The capacitor for power-factor correction is arranged in *parallel* with its motor load; while the series capacitor, as its name implies, is connected in *series* with a transmission or distribution line. It handles the full-line current at the point where it is placed, and is designed so that the voltage rise due to the current passing through it will neutralize all or part of the voltage drop due to the reactance of the line (or even more).

Uses of the Series Capacitor on Rural Lines

The accepted method for voltage regulation on a rural line is the use of the induction feeder voltage regulator. Difficulties arise when an attempt is made to give proper voltage at all points of a long, heavily loaded feeder, because the voltage at points near the substation becomes too high. It is possible to deal with the problem by placing regulators at several points along the line, and distributing the total amount of voltage boost between them. However, such a solution would not often be practical owing to the high cost of the regulators and the increased number of possible points for expensive failures, often at inaccessible places. The series capacitor has been put forward as a possible answer to this problem. Among the objects aimed at by its use are the following:

(*a*). Automatic regulation of voltage at end of line by a bank of capacitors at the substation end.

(*b*). Automatic regulation of voltage at all points on line between definite limits, by capacitors placed at several points along line.

(*c*). Improvement of voltage on a fully loaded circuit to make possible the picking up of additional load, or to eliminate voltage complaints with the existing load.

(*d*). Economy in first cost of a new circuit, by making possible the use of a smaller size of wire for a given number of kw.-miles with a given voltage drop.

(*e*). Possibility of providing for much greater future increases of load or circuit length (with the original voltage drop) than could be handled by increasing the wire size.

The Device in Practice

Considerable experience has been gained with a series capacitor in use at the Ballston substation of New York Power and Light Corporation, for a period of about two years on a 33-kv. transmission line.

On rural lines, however, the use of the device is theoretical as yet. An installation on a 13.2-kv. rural line in the territory of the Central Hudson Gas and Electric Corporation is about completed, and similar installations are being considered by other companies.

Since the maximum voltage across a series capacitor is normally only a small percentage of the line voltage, and varies directly with the current, it is necessary to protect the device against excessive voltages due to short-circuits, or fault currents passing through it. In one method used for this purpose, a spark gap shunted across the capacitor arcsover at a predetermined voltage. Immediately afterwards, a contactor in parallel with the spark gap and capacitor closes, short-circuiting both. As soon as the excessive current ceases, the contactor opens and normal operation is resumed.

Automatic protection must also be provided against breakdown of the dielectric of the capacitor. One method consists in balancing the currents in two

TABLE A

IR Drop in Per Cent of Receiver Voltage	LINE DROP IN PER CENT OF RECEIVER VOLTAGE WHEN ALL REACTANCE IS NEUTRALIZED BY SERIES CAPACITORS										
	LOAD POWER-FACTORS										
	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%
1	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4
2	2.0	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.1	0.9
3	3.0	2.8	2.7	2.5	2.4	2.1	2.1	2.0	1.8	1.6	1.4
4	4.0	3.7	3.6	3.4	3.2	2.9	2.8	2.6	2.4	2.2	2.0
5	5.0	4.7	4.5	4.4	4.0	3.7	3.6	3.3	3.0	2.8	2.5
6	6.0	5.7	5.5	5.2	4.8	4.5	4.4	4.0	3.7	3.4	3.1
7	7.0	6.6	6.4	6.0	5.6	5.2	5.0	4.7	4.3	3.9	3.6
8	8.0	7.6	7.3	6.9	6.5	6.0	5.8	5.4	5.0	4.6	4.2
9	9.0	8.5	8.2	7.8	7.4	6.8	6.5	6.0	5.6	5.2	4.7
10	10.0	9.5	9.1	8.6	8.2	7.7	7.3	6.7	6.3	5.8	5.4
15	15.0	14.4	13.7	13.0	12.4	11.6	11.0	10.3	9.6	9.0	8.4
20	20.0	19.2	18.4	17.5	16.6	15.7	14.9	14.0	13.1	12.3	11.4
25	25.0	24.0	22.9	21.9	20.8	19.9	18.9	17.8	16.7	15.6	14.6
30	30.0	28.7	27.6	26.5	25.2	24.0	22.9	21.6	20.4	19.1	17.9
35	35.0	33.5	32.4	30.9	29.6	28.3	27.0	25.5	24.2	22.7	21.3
40	40.0	38.4	37.1	35.6	34.1	32.6	31.1	29.6	28.0	26.4	24.8

groups of the units of which the capacitor is composed. Normally the currents in similar groups are equal, but if one group breaks down, the currents become unequal, and the differential current can be made to operate a relay which by-passes the capacitor until repairs are made.

Theoretical Studies

Included in this report are a number of tables, curves, and other data on the use of series capacitors. To define the rating of a series capacitor, it is necessary to state the circuit voltage and the full-load current for which it is intended, together with its kv-a. capacity. The latter term takes account of the capacitance of the apparatus and therefore the circuit reactance which it can neutralize.

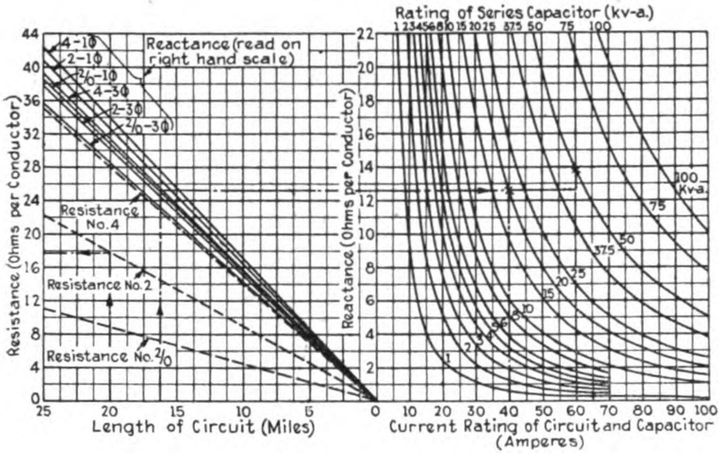


Fig. A. Chart for Use in Choosing Series Capacitors and for Determining Line Resistance and Reactance

Method of using chart: The reactance per conductor of a circuit 16.25 mi. long (No. 2/0 wire, single-phase) is shown to be approximately 12.6 ohms; and if the load is 40 amp., a 20-kv-a. 40-amp. series capacitor will be needed per conductor to neutralize all the reactance. If available, a 25-kv-a. 50-amp. capacitor would neutralize most of the reactance, while a 50-kv-a. 60-amp. capacitor would over-neutralize it. A 10-kv-a. 30-amp. capacitor would also neutralize most of the reactance but would be overloaded. The crosses indicate the ratings in kv-a. and amperes of the capacitors referred to.

The resistance of a circuit 20 mi. long (No. 2 wire) is approximately 17.7 ohms per conductor.

The chain-dotted lines and arrows indicate the steps in the working of these examples.

All values are from Nesbit, 1926 edition, and are for stranded copper conductors. Reactance values are based on single-phase 88-in. spacing and 3-phase 53.3-in. equivalent spacing.

If X is the reactance per leg of the circuit, in ohms, and I the full-load current, in amperes, then $\frac{I^2X}{1000}$ is the kv-a. rating of a series capacitor which will completely neutralize the reactance, leaving only the resistance drop in the circuit.

Fig. *A* gives a series of curves which may be used for quick reference in determining the kv-a. rating of capacitor needed for various lengths of circuit and sizes of wire. An example given on the chart explains the method of use.

Several other things can be done with this chart. For example, the reactance or resistance of various lengths of circuit of different wire sizes can be read directly from it. Finding the resistance in this way and multiplying it by the current rating of the circuit, we can find the per cent resistance drop. Table *A* can then be used to find the per cent line drop at any power-factor when the line reactance is neutralized by series capacitors. Returning to Fig. *A*, we can proceed to find the kv-a. rating of suitable series capacitors.

Table *B* gives the kw.-miles rating of a circuit under the conditions set forth both with and without series capacitors. It also shows the per cent increase in kw.-miles which is made possible by the series capacitors, together with the kv-a.-miles of series capacitors required per leg of the circuit.

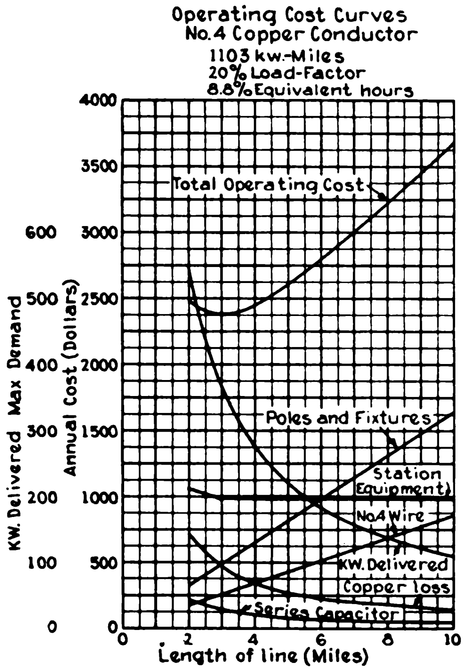


Fig. B. Operating Cost Curves for Series Capacitors in Various Lengths of 4-kv. Distribution Circuits. 3-phase 60-cycle 33.6-in. equivalent spacing, 0.75-p-f., 10 per cent full-load voltage drop. Series capacitor at substation neutralizes all line reactance

TABLE B

Increase in kw.-miles for same per cent. Voltage drop, using series capacitors that neutralize all the line reactance; also size of series capacitors and size of induction voltage regulators giving equivalent results, expressed in kv-a.-miles.

60 Cycles—75 Per Cent Power-factor—10 Per Cent Voltage Drop

Wire Size A.W.G. (Copper)	KILOWATT-MILES Without Series Capacitors	KILOWATT-MILES With Series Capacitors	Per Cent Increase in Kw.-miles with Series Capacitors	Kv-a.-miles of Series Capacitors	Kv-a.-miles of Regulators
2300 Volts—Single Phase—88-in. Spacing					
				One Unit, Totalling	
6	90	115	28	7.8	4.8
4	125	182	46	19.0	11.8
2	168	290	72	46.4	28.8
1/0	214	461	115	112.8	72.0
2300 Volts—Three Phase—53.3-in. Equivalent Spacing					
				Three Units, Each of	
6	182	230	26	4.8	3.4
4	256	365	42	11.7	8.3
2	348	580	66	28.5	20.5
1/0	452	922	104	69.3	51.2

Based on capacitors located at substation or in line ahead of all load, so that they handle the full-load current.

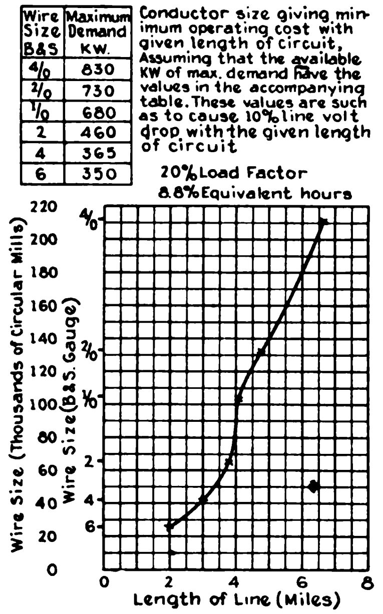
For 5 per cent voltage drop the values of kw.-miles are approximately half, and of kv-a.-miles approximately one-quarter, those given above.

Fig. *B* shows how the operating cost of a circuit in which series capacitors are used varies with the length of circuit.

This operating cost is taken to include the following:

Carrying charges on series capacitor, at 15 per cent.

Carrying charges on copper wire, at 10 per cent.



Wire Size B&S	Maximum Demand KW.
4/0	830
2/0	730
1/0	680
2	460
4	365
6	350

Fig. C. Curves for Determining Conductor Size for Circuit Conditions of Fig. B

Carrying charges on poles and fixtures, at 12 per cent.

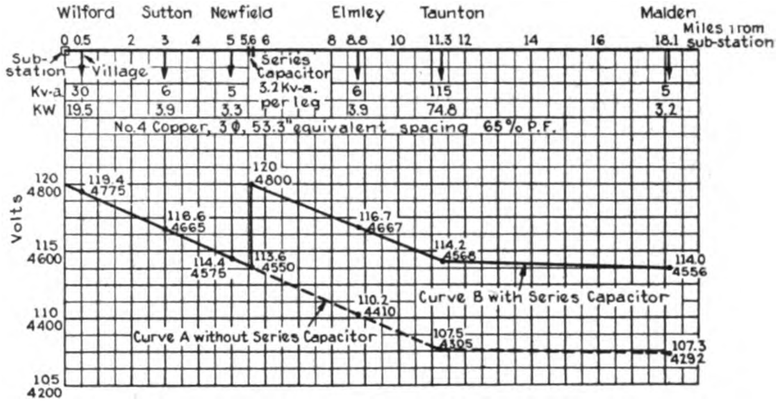
Carrying charges on substation equipment (oil circuit-breaker, regulators, reactors, etc.) at 12 per cent.

Each of these items, together with the total operating cost and the kilowatts delivered, is separately plotted in Fig. *B* against the length of the circuit in miles. The conditions are given in the tabulation accompanying the curves.

It will be noted that the total operating cost under these conditions is a minimum for a line three miles long. This particular set of curves is for No. 4 copper wire. Similar curves have been plotted for other sizes from No. 6 to No. 4/0; and in each case a well-marked minimum is noticed in the total operating cost curve. In Fig. *C* the sizes of wire are plotted against the length of circuit at which the minimum operating cost is obtained, assuming that the available kilowatts of maximum demand are such as to give 10 per cent line voltage drop.

Lastly, as a practical example of the use of series capacitors on rural lines, the following is given:

Fig. *D* shows the distances, wire sizes, and loads on a 4600-volt rural line. Curve *A* on this chart shows the existing voltage gradient. It will be seen that the voltage drop is entirely too large. By the use of a bank of series capacitors 5.6 mi. from the substation, 3.2 kv-a per leg, the voltage gradient can be improved as shown in Curve *B*.



Effect of Series Capacitor on Voltage Gradient

Fig. D. Distances, Wire Sizes, and Loads on a 4600-volt Rural Line

The cost of the series capacitors will be about $2500, whereas the cost of suitable regulators would be about $3200. Of course, the regulators would compensate for variations in bus voltage as well as line drop, while the capacitors can only take care of the reactive component of the latter. The capacitors, however, will have lower losses.

The Committee is indebted to Mr. F. la T. Budgett, Distribution Engineering Department, New York Power and Light Corporation, for preparation of the data and curves used in this report.

The Constant-air-weight Method of Cupola Blowing

PART I

THE FUNDAMENTAL REQUIREMENTS OF IRON MELTING IN CUPOLAS

By H. V. CRAWFORD

Industrial Department, General Electric Company

> *The method of supplying cupola air by weight instead of by volume is almost revolutionary, though so logical that the wonder is that it has not always been in use. Mr. Crawford, who received in 1929 a Charles A. Coffin Award for developing the method, here outlines cupola operation; later the electrical equipment, whereby the proper weight of air is automatically supplied, will be described.*
>
> —EDITOR

FOR a great many years cupolas have been operated either on the basis of holding a constant wind box pressure or of supplying a constant volume of air. The new method involves the supplying of a constant weight of air. The logic is very simple: The air is used to support combustion in the cupola, which is the union of the carbon of the fuel with the oxygen of the air. These substances combine to form gases always in proportion to their atomic weights, or total actual weights by atoms, pounds, or tons. The air and the fuel should, therefore, be supplied by weight, just as in most cases the coke is charged; but previous to the introduction of the constant-weight cupola blower with automatic control it was not possible to furnish the air in this manner.

In order to supply a constant weight of air giving a constant weight of oxygen it is necessary under usual conditions to be able to vary the volume approximately one-third, as the volume of one pound of air varies directly with the absolute atmospheric temperature and indirectly with the atmospheric pressure.

The idea of using constant weight instead of constant volume followed a special study of the air requirements of a cupola based upon knowledge relating to the compressing and handling of air gained in long experience building blowers. The subject was, therefore, approached from an "air" viewpoint; and during this study the importance of the problem of proper air supply to the cupola was realized. The designers of the new equipment, working in combination with the foundry, then ran a series of tests which indicated very emphatically that the cupola should be supplied with a constant weight of air in order to get consistent results and the best efficiency in the use of the fuel.

The next step was the development of a blower and control equipment which would automatically supply a constant weight of air to the cupola under all conditions.

COMBUSTION IN THE CUPOLA

The operation of the cupola being chiefly a process of combustion, a study of combustion in the cupola should be made, regarding which very complete information is contained in a number of volumes. Dr. Richard Moldenke covers the subject of combustion as related to the cupola very thoroughly in his volume, *Principles of Iron Founding*, and Dr. E. E. Marbaker has recently written a very fine paper on this subject.

However, practically all of the books and articles written on this subject previous to the paper read by the writer before the American Foundrymen's Association in May, 1928, failed to emphasize the fact that a *constant weight* of air should be used instead of a constant volume, although all the calculations are started on the basis of the weight of carbon and oxygen required.

Mr. Lawrence A. Hartley has recently published a new volume, *Elementary Foundry Technology*, with special reference to gray iron and steel in which he brings out very emphatically the importance of using a constant weight instead of a constant volume of air. Mr. J. E. Hurst, an English author, also covers this point in a recent revision of his volume dealing with foundry practice.

Amount of Air Required: Volume Method

In order to arrive at the amount of air required it is necessary to use only very simple laws covering the union of the carbon of the coke and oxygen of the air. One atom of carbon combines with two atoms of oxygen.

$C+O+O=CO_2$ or $12+16+16=44$ or

32 parts of oxygen to 12 parts of carbon.

$32 \div 12 = 2.66$ or 2.66 times as much as carbon.

Therefore, to burn one pound of carbon to CO_2, 2.66 pounds of oxygen will be required. Air contains by weight 23.1 per cent oxygen, giving $2.66 \div 0.231 = 11.517$ as the pounds of air required for the perfect combustion of a pound of carbon.

Previous methods of figuring changed at this point from weight to volume by dividing 11.517 by 0.0765, the weight of a cubic foot of air at 60 deg. F. and atmospheric pressure. This gives a factor of 150; and with a ratio of iron to coke of 10 to 1 in the charges 200 pounds of coke will be required to melt a ton (2000 lb.); therefore, the volume of air required to melt a ton of iron is $150 \times 200 = 30{,}000$ cubic feet.

Such has been for a great many years the general rule for figuring the amount of air required; in fact, so general has it become that in many cases it has been used without considering that it is based on a fixed ratio of iron melted to coke burned in the charges. Actually, this amount of 30,000 cu. ft. is based on the following:

Perfect combustion; all carbon burned to CO_2
Iron-to-coke ratio, 10 to 1.
No air leakage.
Coke 100 per cent carbon.
Coke 100 per cent dry.
Atmospheric pressure, 14.7 lb. per sq. in.
Atmospheric temperature, 60 deg. F.
Humidity, zero.

All of these conditions change, and later on it will be shown that under certain conditions 30,000 cu. ft. would be almost twice as much air as is actually required. The old method is, therefore, decidedly incorrect; and the proper method is to compute the amount from start to finish in pounds, and to take into account all the foregoing variable considerations.

Amount of Air Required: Weight Method

Carbon Burned to CO_2. In the weight method, consideration is given to all factors entering into cupola operation and in order to arrive at the pounds of air required it is first necessary to determine the amount of carbon burned to CO_2. The air from the blower passes through the tuyeres into the bed of the cupola and comes in contact with the incandescent coke; when the oxygen of the air unites with the carbon of the coke and forms CO_2 each pound of carbon so consumed evolves 14,550 heat units. Of this weight of air 23.1 per cent is used in this manner and the other 76.9 per cent (practically all nitrogen, an inert gas) absorbs heat until it reaches the maximum temperature in the cupola and passes up the stack, carrying a certain amount out of the top depending upon the opportunity it has to impart its heat to the upper charges of coke and iron.

The CO_2 formed travels up with the nitrogen, and as it comes in contact with incandescent coke further up or further into the bed or in the upper coke charges, some of the oxygen combines with the carbon in the coke and CO is formed, according to the formula

$$CO_2 + C = 2\ CO - 5850\ \text{B.t.u.}$$

This occurs in the bed when it is too high, or the amount of oxygen is too low, or the air does not penetrate into the bed far enough; and each pound of carbon thus consumed absorbs heat to the extent of 5850 heat units, and therefore actually has a cooling effect, under the conditions existing in the bed at this point. However, it is possible that some oxygen will be present, and combining with part of the CO gas ($2\ CO + O_2 = 2\ CO_2 + 10{,}200$ B.t.u.). Thus 10,200 heat units will be added, and the net result will be the addition of $10{,}200 - 5850 = 4350$ heat units, whereas burning to CO_2 would give 14,550, incurring a loss of 10,200 B.t.u.

When the CO does not have any oxygen to combine with it, the actual loss for each pound thus consumed is the 5850 B.t.u. required in the foregoing reaction in addition to the 14,550 B.t.u. that the complete combustion of the carbon would have produced, or a total loss of 20,400 B.t.u. This is what happens in the charge above the bed, where there certainly should not be any oxygen to combine with the CO; so that for every pound of carbon that burns before it reaches the bed, this loss of 20,400 heat units will occur. Such losses cannot be completely eliminated, but can be reduced to a minimum by having the proper height of bed, the proper amount of oxygen distributed as evenly as possible over the bed, and the proper charges to maintain the bed as nearly the same height as possible. As long as free oxygen exists in the bed the amount of CO gas formed will be a minimum, and some of this taking up oxygen of the air will reduce the total loss. A high bed or a low amount of air means that part of the way up in the bed there is no oxygen; only CO_2 which, coming in contact with carbon at high temperature, rapidly forms CO. With the bed of proper height and the right amount of air, a minimum of CO gas will be formed in the bed and the loss will be confined to the upper charges. Beyond a certain amount of air and coke burned in the bed for a cupola of given size the efficiency will be lowered in consequence of the larger amount of CO_2 formed in the bed which causes more of the carbon above the bed to be burned to CO; and further because of the fact that the larger amount of air and gases causes the hot gases to travel faster and thus more heat is carried out the top of the cupola.

Such considerations show the importance of supplying the right amount of air and at the same time indicate the difficulty in determining this amount. In figuring the amount of air, allowance should be made for the amount of carbon burned finally to CO by the oxygen from the CO_2, because the amount of coke thus consumed does not get its oxygen from the incoming air. An analysis of the stack gases will indicate very closely the amount of coke being burned to CO and therefore for certain operating conditions a fairly close calculation of the amount of air required can be made.

According to Dr. Moldenke one-third of the carbon will be burned to CO in good practice, one-seventh in best practice, and as much as two-thirds in poor practice. Therefore, for poor practice the amount of coke will be high, or the ratio of iron to coke low; and as the practice improves the ratio will increase. This indicates that the amount of carbon burned to CO_2 will vary directly with the ratio of iron to coke in the charges. More oxygen will be required as more carbon is burned to CO_2; but owing to the reduction in total carbon required to give best results the air will be reduced. Calculations and tests indicate that the amount of air required is reduced as the ratio of iron to coke is incresaed.

Carbon in Coke. In figuring the amount of air it is necessary to allow for the percentage ash and volatile matter in the coke; but good coke averages about 88 per cent fixed carbon. Where the amount varies from this figure it is necessary to change the amount of air.

Moisture in Coke. The coke should be stored in a dry place and then charged by weight; but if wet, allowance should be made for the water content. This is hard to determine, so that under this condition it is best to charge by volume although by weighing at frequent intervals some of the coke that has been dried the effective weight of coke can be determined.

Density and Size of Coke. The density and size of the coke and whether the coke is screened will affect the amount of air required per minute. However, good coke, properly screened, can be secured; therefore, these factors need not be taken into consideration until such a time as some of the other factors affecting cupola operation are controlled to a much closer degree. The coke should be in pieces as near the same size as possible as large pieces will burn slower and small pieces faster thus affecting the rate at which the air should be furnished.

Air Leakage Between Blower and Bed. The air leakage is one of the easiest factors to control and should be confined to that escaping through the slag hole. With slag running continuously while the blower is running, which is essential for best operating conditions, the leakage will be very small. There is no excuse for the piping not being air-tight but leakage will occur if ordinary slide gates are used in the piping system. Hand gates of the damper type and of the same construction as the automatic gates are practically air-tight inside and outside. An ordinary slide gate two feet wide may have a leakage as high as 500 to 700 cu. ft. per min.

Leakage may also occur between the shell and the brick lining if the tuyeres are not installed properly. The tuyere sight-hole covers should be made air-tight by the use of castings having a groove filled with packing to fit over the edges of the opening.

Generally, five per cent leakage is allowed but this will vary, depending on the tightness of the system.

Humidity. Under ordinary conditions the air will carry only a small amount of water vapor. The humidity of the atmosphere changes with the weather and there will be a change in the density of the air which will involve a change in the oxygen content. Thus there will be an error at one extreme (when no water vapor at all is present) of 0.3 per cent; and at the other extreme (a very hot, humid day) of 1.5 per cent. Water vapor still contains some oxygen, so that the maximum error is something less than 1.5 per cent. This error is very small as compared with an error of over thirty per cent made under average weather conditions when a constant volume of air is supplied to the cupola.

Foundrymen who have operated their cupolas on the basis of supplying a constant volume of air have always noticed a difference in the operation of their cupolas on a rainy day in the summer time. The difference is due to the fact that the air is cooler and contains more oxygen per cubic foot and not because of more moisture in the air. There is even less moisture under these conditions, as the humidity varies with the temperature of the air.

Ratio of Iron to Coke Charges. In figuring the amount of air required, the ratio of iron to coke is the weight of iron in each charge divided by the weight of coke in each charge, and therefore does not include the bed charge. Dividing the number of pounds of iron melted by the ratio gives the number of pounds of coke burned, which must be known before the amount of air can be figured. In present-day usage in this sense, the meaning of "ratio" is obscure. In some cases it is the overall ratio of the entire plant, or the total pounds of iron charged in a whole month divided by the total pounds of coke purchased. Such a ratio is variable and therefore as a basis of comparison between any two plants or any two cupolas is meaningless, and useless in figuring the amount of air. A ratio on this basis will depend on the coke lost in transit, the amount of coke breeze, the weight of the coke bed, the number of cupolas operating, the tons of iron melted each day, the number of days operating, the amount of fresh coke used in the core ovens or for any other purpose, and the way the dump coke is used. A small plant may be operating much more efficiently than a large plant and yet the overall plant ratios may be about the same.

Similarly, one cupola may be operating more efficiently than another but if the first is operating only three or four hours whereas the other one is operating eight hours, the ratio may be the same for both if the bed is included. In both cases the amount of coke unburnt or the drop coke should be about the same.

In order to figure the amount of air and to make a comparison of efficiencies, the coke ratio should be taken as the ratio between charges less the bed charge; and any dump coke used should be charged on the basis of allowing about 10 per cent of the weight for moisture and drops of slag and iron.

The purpose of introducing coke and air is to produce a sufficient number of heat units to melt and superheat the iron to the proper temperature so that it will mix and flow properly. The amount of coke required will therefore depend on the character of the iron charges, the temperature required at the spout and the loss of heat through the lining, up the stack, and in the limestone and slag.

Assuming no loss, perfect combustion, and that coke is 100 per cent carbon, the consumption of one pound of coke would make available 14,550 heat units (B.t.u.); thus on the basis of 600 heat units being required to melt and superheat a pound of iron to 2850 deg. F. it should be possible to melt 14,550÷600=24.25 or approximately 25 lb. of iron, a ratio of 25 to 1. At 2400 deg. F. only about 490 B.t.u. are required per pound of iron, so that the ratio becomes 14,550÷490=29.7, or approximately 30 to 1.

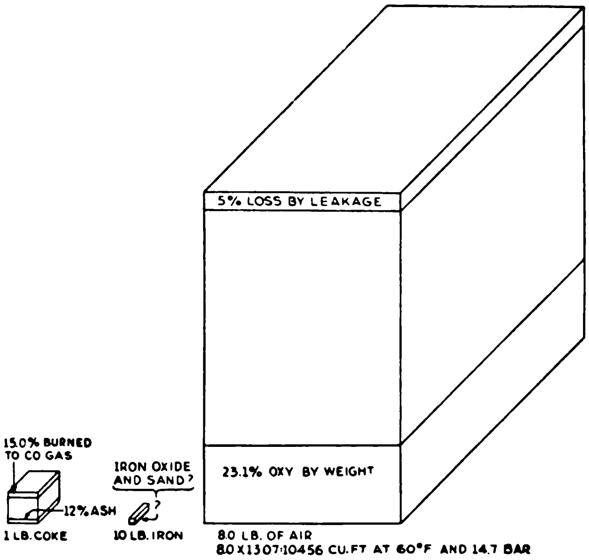


Fig. 1. Graphical Representation of the Materials Entering Into the Cupola During the Charging and Melting Process

In view of these considerations it would seem that a ratio between the charges of at least 10 to 1 should be secured in any case, and in practically every case where an effort has been made to supply the proper amount of oxygen at all times a ratio at least this high is maintained. This includes cases where the mixture contains 20 per cent steel and a large amount of foreign scrap, and where the iron is running 2750 deg. F. at the spout, unoxidized and melted at the rated capacity of the cupolas, the capacity in most cases running as high as 18 to 20 tons per hour and operating 8 to 10 hours per day.

With 20 per cent steel mixture, but where the temperature of 2650 deg. F. at the spout is satisfactory, 12 and 13 to 1 ratios are being secured. With lower spout temperatures, no steel, and higher phosphorous content, ratios of 14 to 1 are being secured in both large and small cupolas and ten-hour melts.

An iron-to-coke ratio of 10 to 1 in the charges is considered average, 12 to 1 very good, and 14 to 1 about the best that can be expected with our present knowledge and design of cupolas.

Comparison of Materials Charged. On the basis of a 10 to 1 ratio a comparison of the amount of iron, coke, and air charged into the cupola will be interesting and will emphasize the importance of using the correct amount of air. This is shown in Fig. 1. The block on the right shows the relative space occupied by the 8.0 lb. of air required to burn 1.0 lb. of coke and melt 10 lb. of iron. One pound of air at 60 deg. F. and 14.7 lb. per sq. in. barometer occupies 13.07 cu. ft. so that 104.56 cu. ft. of air are required per pound of coke. The portion blocked off at the bottom shows the corresponding amount of oxygen, which is 20.9 per cent by volume or 23.1 per cent by weight, or the proportion of the total air charged used for combustion. The other 76.9 per cent, largely nitrogen, to a certain extent defeats the purpose for which air is charged into the cupola. The part blocked off at the top shows the amount lost by leakage.

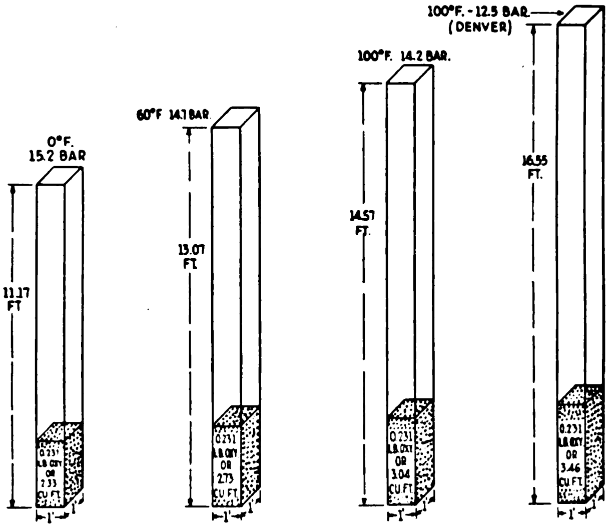

0°F. 15.2 BAR
11.17 FT
0.231 LB OXY OR 2.33 CU FT
60°F 14.7 BAR
13.07 FT
0.231 LB OXY OR 2.73 CU FT
100°F. 14.2 BAR.
14.57 FT.
0.231 LB OXY OR 3.04 CU FT
100°F. - 12.5 BAR (DENVER)
16.55 FT.
0.231 LB OXY OR 3.46 CU FT
1'
1'

Fig. 2. Graphical Representation of the Changes in Volume of Air Under Different Conditions of Atmospheric Temperature and Pressure

The block at the left shows the relative space occupied by a pound of coke, the lower section of which shows a loss of 12 per cent on account of ashes and the upper section a loss of 15 per cent on account of the part burned to CO instead of CO_2.

The small block of iron weighs ten pounds and has a very small percentage loss due to rust and sand. Therefore, about 75 per cent of the coke and iron charged accomplishes the purpose for which it is charged, whereas only about 23 per cent of the air does effective work. The weight of the air is almost as much as the combined weight of iron and coke; by the volume method it is actually more.

Temperature and Barometer. Fig. 2 illustrates very clearly that constant weight of air is not necessarily constant volume, and that the air should be figured by weight instead of by volume in order to provide a constant weight of oxygen. For constant weight, the volume varies directly with the absolute temperature and inversely with the barometric pressure. This chart shows that at 60 deg. F. and at a barometric pressure of 14.7 lb. per sq. in. (standard conditions) 1.0 lb. of air occupies 13.07 cu. ft. At 0 deg. and 14.7 lb. the air is contracted so that 1.0 lb. now occupies $460/520 \times 13.07 = 11.56$ cu. ft. At this temperature the pressure may be as high as 15.2 lb. per sq. in., when 1.0 lb. of air will occupy $14.7/15.2 \times 11.56 = 11.17$ cu. ft. This still gives a constant weight of 0.23 lb. of oxygen, but the volume has decreased to $0.209 \times 11.17 = 2.33$ cu. ft.

At 100 deg. F. the pound of air is expanded to $560/520 \times 13.07 = 14.08$ cu. ft. and at this temperature the barometer may show a pressure as low as 14.2 lb. per sq. in., in which case 1.0 lb. of air will occupy $14.7/14.2 \times 14.08 = 14.57$ cu. ft. and the volume of oxygen will be $0.209 \times 14.57 = 3.04$ cu. ft.

The right-hand column in the chart shows the probable maximum requirements in this country. For instance, in Denver (Colo.), where the summer temperature may be as high as 100 deg. and where the barometric pressure is normally 12.5 lb. per sq. in., the volume occupied by 1.0 lb. of air is $460/520 \times 13.07 \times 14.7/12.5 = 16.55$ cu. ft. In this case the volume of oxygen is $0.209 \times 16.55 = 3.46$ cu. ft.

Thus supplying a constant volume of air to the cupola will not produce consistent melting results on account of the changes in atmospheric conditions from hour to hour, day to day, and month to month, because these vary the amount of oxygen.

At zero and 15.2 lb. per sq. in. barometer, 11.17 cu. ft. of air is required, while at 100 deg. and 14.2 lb. per sq. in., 14.57 cu. ft. is required. This means that, in the winter, 14.57 cu. ft. is 30 per cent too much air. The amount required at Denver in summer as compared with amount required at sea level at zero and 15.2 lb. per sq. in. is $16.55/11.17 = 1.49$, or approximately 50 per cent excess.

Fig. 3 gives factors for determining the volume of air required at various temperatures and barometric pressure for a constant amount of oxygen, based on standard conditions (60 deg. F. and 14.7 lb. per sq. in. barometer). This shows, by applying these factors to an actual case where the cupola is melting 14 tons per hour and 7000 cu. ft. is required at 60 deg. and 14.7 lb. per sq. in., that at zero degrees and 15.2 lb. per sq. in. only 6000 cu. ft. is required; at 100 deg. and 14.2 lb. per sq. in., 7700 cu. ft.; while at Denver at 100 deg. and 12.5 lb. per sq. in. the amount is 8860 cu. ft.

Pounds of Air Required per Minute

In figuring the amount of air required in pounds per minute it is necessary to take into consideration the following important factors:

2.66 = lb. of oxygen required per lb. of carbon
0.231 = lb. of oxygen per lb. of air.
11.517 = lb. of air per lb. of carbon ($2.66 \div 0.231$)
C = per cent fixed carbon per lb. of coke
M = dryness factor of coke charge (in per cent)
Y = per cent carbon burned to CO_2.
A = per cent air from blower reaching bed
T = tons of iron melted per hour
R = ratio of iron to coke in charges, by weight

The following formula can then be used:

Pounds of air required per minute

$$= \frac{11.517\,CMYT}{60\,AR} \times 2000 = \frac{385\,CMYT}{AR}.$$

If the coke is dry and the leakage is average, M will become unity, A will be 0.95, and the formula will be reduced to

$$\frac{406\,CYT}{R}$$

Using an average value of C as 0.88, it reduces to

$$\frac{357\,YT}{R}$$

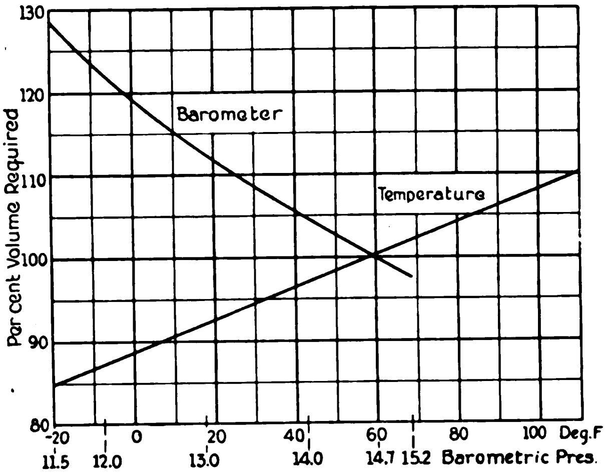


Fig. 3. Chart of Factors to Correct for Variations of Temperature and Pressure from Normal (60 deg. F. and 14.7 lb. per sq. in.) in Determining the Volume of Air Required to Yield a Given Quantity of Oxygen

Recent tests indicate that, with a 12 to 1 ratio between charges, 85 per cent of the carbon is burned to CO_2; at 10 to 1, about 75 per cent; and as the ratio was reduced this percentage was reduced about five per cent for each unit reduction in the ratio. The accompanying tabulation (Table I) which is based on the preceding calculations and assumptions, indicates the amount of air required for various ratios.

TABLE I

POUNDS OF AIR PER MINUTE PER TON OF IRON MELTED PER HOUR

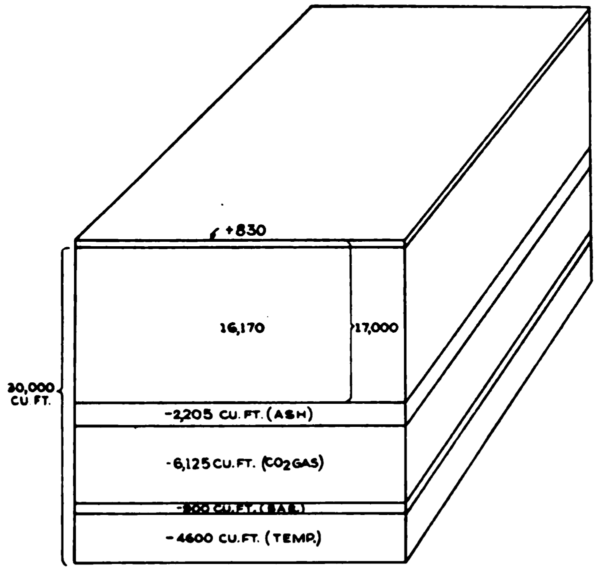
Ratio	Value of Y	Lb. Air Per Min.
12 to 1	0.85	25.3
11 to 1	0.80	26.0
10 to 1	0.75	26.8
9 to 1	0.70	27.8
8 to 1	0.65	29.0
7 to 1	0.60	30.6

The fact that only five per cent leakage is allowed should be emphasized; and in case the wind box, pipe line, and gates are not tight and a big slag hole is used, it will be necessary to increase these figures.

Comparison of Volume and Weight Methods

Table II gives the amount of air per ton of iron melted, using both the weight method and the volume method, based on standard conditions of 60 deg. F. and 14.7 lb. per sq. in. barometer.

The cu. ft. values under the weight method are the lb. of air divided by 0.0765 (the weight of a cu. ft. of air at standard condition of 60 deg. F. and 14.7 lb. per sq. in.). The volume method values are based on the old rule of 30,000 cu. ft. per ton with ratio of 10 to 1, and as the ratio is increased or decreased the amount of air is decreased or increased respectively.



Reduction due to -20° temp. gives $30{,}000 \times \frac{440}{520} = 25{,}400$

Reduction due to 15.2 bar. gives $25{,}400 \times \frac{14.7}{15.2} = 24{,}500$

Reduction due to 75% of coke burned to CO_2 gives 24,500 × 0.75 = 18,375
Reduction due to 12% ash in coke gives 18,375 × 0.88 = 16,170
Addition for 5% air leakage gives 16,170 + 0.95 = 17,000
30,000 + 17,000 = 1.765, or approximately 75% excess

Fig. 4. Graphical Representation of the Various Excesses Occasioned in the Use of an Arbitrary Volume of 30,000 cu. ft. of Air Per Ton of Iron Instead of the 17,000 cu. ft. Actually Required at 20 deg. F. and 15.2 lb. per sq. in.

Fig. 4 emphasizes the error made in using 30,000 cu. ft. of air per ton of iron based on a 10 to 1 ratio. This diagram represents the error thus made in an actual case when the temperature is 20 deg. F. below zero and the barometer indicates 15.2 lb. per sq. in. The reduction in the volume of 30,000 cu. ft. due to -20 deg. temperature gives 30,000×440/520 = 25,400 cu. ft., which, owing to the higher pressure (15.2 lb. per sq. in. barometer) becomes 25,400×14.7/15.2 = 24,500. The reduction due to incomplete combustion (only 75 per cent of coke is assumed to have burned to CO_2) gives 0.75×24,500 = 18,375 cu. ft. A further reduction due to ash in the coke gives 18,375×0.88 = 16,170. Addition for leakage gives finally 16,170÷0.95 = 17,000 cu. ft., whence 30,000÷17,000 = 1.765, showing approximately 75 per cent more than required.

TABLE II

AMOUNT OF AIR REQUIRED PER TON

Ratio	Method		
	Constant Weight		Constant Volume
	Lb. of Air	Cu. Ft. at 60 deg. F. and 14.7	
12 to 1	1518	19,860	25,020
11 to 1	1560	20,400	27,300
10 to 1	1608	21,000	30,000
9 to 1	1668	21,840	33,300
8 to 1	1740	22,740	37,500
7 to 1	1836	24,000	42,900

Certain types of blowers and certain types of meters have been developed with the idea of securing constant volume. However, even the perfect operation of these machines and meters will give the serious discrepancies illustrated at one extreme or the other so that, even if there were some perfect means of supplying a cupola with a constant volume of air, and if this volume were exactly correct at one extreme, it would be seriously in error at the other.

Effect of Excess Oxygen

For perfect combustion, a definite weight of oxygen should combine with a definite weight of carbon in the coke to give carbon dioxide gas in the melting zone. Thus if too much oxygen is supplied, free oxygen will exist and combine with the iron in the melting zone; the result is oxidized or burnt iron. Furthermore, the excess oxygen carries more nitrogen which increases the cooling action, so that the iron is not only burnt, but is cold. Twenty-three per cent of the air is oxygen, which is the agent promoting combustion, and the other 77 per cent is largely nitrogen and inert gas which is heated to the maximum temperature in the cupola and then discharges into the atmosphere having done but very little work. As it passes through the successive layers of iron and coke it gives up some heat; but with excess air it travels at such a high velocity it has time to give up only a small percentage of its total heat content. Excess oxygen, therefore, means not only oxidized iron but the iron is cold and spongy; and excess air not only increases the speed of blast but causes high wind box pressure and greater burning of the lining.

Effect of Insufficient Oxygen

Insufficient oxygen means that the oxygen is all consumed in combining with the coke in the lower part of the layer of coke just at the melting zone. Carbon dioxide is formed but of an insufficient amount, which encountering the incandescent coke in the upper part of the layer of coke just under the melting iron is converted into carbon monoxide gas, and each pound of carbon thus consumed robs the bed of 5850 B.t.u. This occurs in the regions just where the maximum number of heat units to be secured by forming carbon dioxide are required. The result may be both cold iron and slow melting with the possibility of bridges forming. If the bed is high and the ratio low, there may be sufficient air to burn enough coke to CO_2 in the bed to furnish the heat required for melting hot iron; but the melting rate will be low, and a great deal of coke will be wasted.

Method of Operating Cupola

Certain methods of operating cupolas have prevailed for a great many years; yet in no two foundries are the methods alike. The method used on one cupola, while giving good results most of the time, might not work at all in a cupola of the same design in another plant. Obviously, this should not be the case, and some standardized method should be followed.

There has been in the past a great deal of mystery connected with the operation of a cupola inasmuch as it is not possible to see just what is going on inside. Results have varied in different plants and from day to day in the same plant because of the three chief variables, iron, coke, and air, only the first two have been under control and very little effort has been made to control the air, as though the important part that air plays in the successful and consistent operating of the cupola had not been appreciated.

After the calculation of the amount of air required, practical operation involves so many variables that the operator feels that he can be sure of one thing—plenty of air—and, therefore, in most cases uses too much. Too much is the cause of most troubles; and the variation in the oxygen is generally the cause of inconsistent results. Recognizing that air is just as important as coke, although available at only a fraction of its cost, means that the foundryman should have the proper air equipment in order to get the best results. Using the constant-weight cupola blower with automatic control makes it readily possible for him to determine the correct amount of air, after which the apparatus can be set to automatically supply day in and day out the correct amount of air irrespective of the changes in the temperature of the air, barometric pressure, and ordinary changes in resistance to the flow of air through the cupola. In the development of this apparatus and the installation of about 150 equipments a great deal of experience has been gained; and what follows in this article deals with the various factors which bear an important relation to more successful cupola operation.

Best Operating Results

Ordinarily the first consideration in cupola practice is to secure hot iron, but iron can be hot and still not be of the proper mixture, or it can be hot and still not hold up its heat, and therefore freezes quickly, so that by the time it is ready to pour it is entirely unfit for pouring. The difficulty of improper analysis or mixture and the freezing of the iron is due either to an improper mixture to begin with or too much air burning out the coke, lowering the bed, and therefore burning the iron. Too much air not only changes the analysis but affects the fluidity of the iron and the strength of the resulting casting. Observation of the temperatures by the naked eye or by pyrometer usually indicate whether the iron is hot enough. A better check, however, is to pour samples into a fluidity-test mold, using iron direct from the spout. If iron at this point is satisfactory, defective castings should not be chargeable to the melting of the iron, but rather to mishandling, or other causes.

Best results depend on:

(1). Starting with the right mixture
(2). Starting with a proper bed
(3). Maintaining a proper bed
(4). Starting with the proper supply of air
(5). Maintaining the proper supply of air;

and are indicated by:

(1). Consistent analysis of melted iron
(2). Consistent temperature of melted iron
(3). Consistent fluidity of melted iron
(4). High iron to coke ratio—at least 10 to 1 in the charges (less bed).

Efficient operation is indicated by the elimination of practically all of the flame at the charging door, when the total charge is 12 to 15 feet deep, and only warm gray smoke rolling up.

Operating More Than One Cupola with One Blower

The blower should supply air to only one cupola at a time, and in case it is used to supply air to a certain size cupola on one day and a larger or smaller cupola on the next, it should of course be large enough for the large cupola and then run at a lower rating on the smaller cupola. The piping in this case should have, in addition to the automatic blast gate, properly designed hand gates of the damper type to direct the flow of air into either cupola, as desired. The damper-type gates are of the same construction as the automatic gates and are practically air tight. These should be used instead of the ordinary slide gate which may permit the outward leakage of a large amount of air, not only occasioning great waste, but making it very difficult to determine the correct amount of air to use in order to make up for that which is being lost. An ordinary slide gate 2 ft. wide may have a leakage from 500 to 700 cu. ft. per min.

Tuyeres

The construction of the tuyeres should be such that the air is evenly distributed around the cupola and they should have the proper height to give enough velocity to the required air to cause it to penetrate into the center of the cupola. They should be continuous and have a height from two to six inches. The smaller the height, the higher is the velocity of a given amount of air and, therefore, the better is the penetration. Changing the height has no appreciable effect on the wind box pressure for a given amount of air, because the length of the path the air has to travel passing through the tuyeres is very short. Five-inch tuyeres on a cupola with 54 in. inside lining have been plugged with brick down to a height of two inches and no effect on the operation of the cupola, wind-box pressure, or the cutting of the lining determined.

Changing the size of the tuyeres is generally supposed to affect the "speed of the blast" and, for the correct amount of air, varying the height of the tuyere will affect the speed of the air entering the cupola as explained; but the speed of the blast is the amount of gases passing through the bed at any certain plane divided by the area of the open spaces in this plane. For a given area the speed of the blast will be affected only by the amount of air being used.

It is assumed that no upper tuyeres are now being used as it has been determined time and time again that they are not only unessential, but make it necessary to increase the height of the bed an amount equal to the distance between the tops of the lower and upper tuyeres.

Bed

The function of the bed is to develop a sufficient number of heat units to melt a given output of good hot iron in a given time with a minimum waste of heat. Therefore, a certain amount of incandescent coke will require a definite amount of oxygen in a given time, in order to burn the maximum amount of carbon in the fuel to CO_2 and a minimum amount of CO gas, thereby obtaining the best efficiency. Each pound of carbon burned to CO_2 gives 14,550 heat units, whereas every pound burned to CO requires 5850 B.t.u. to complete the reaction, and incurs the loss of heat that would otherwise have been available, as previously shown; therefore the bed of the cupola should be operated like the bed of fire in any furnace, burning the proper amount of fuel and the correct amount of air at all times, thereby securing more heat per pound of fuel and utilizing the heat for the purpose for which it is generated instead of forcing it out the stack.

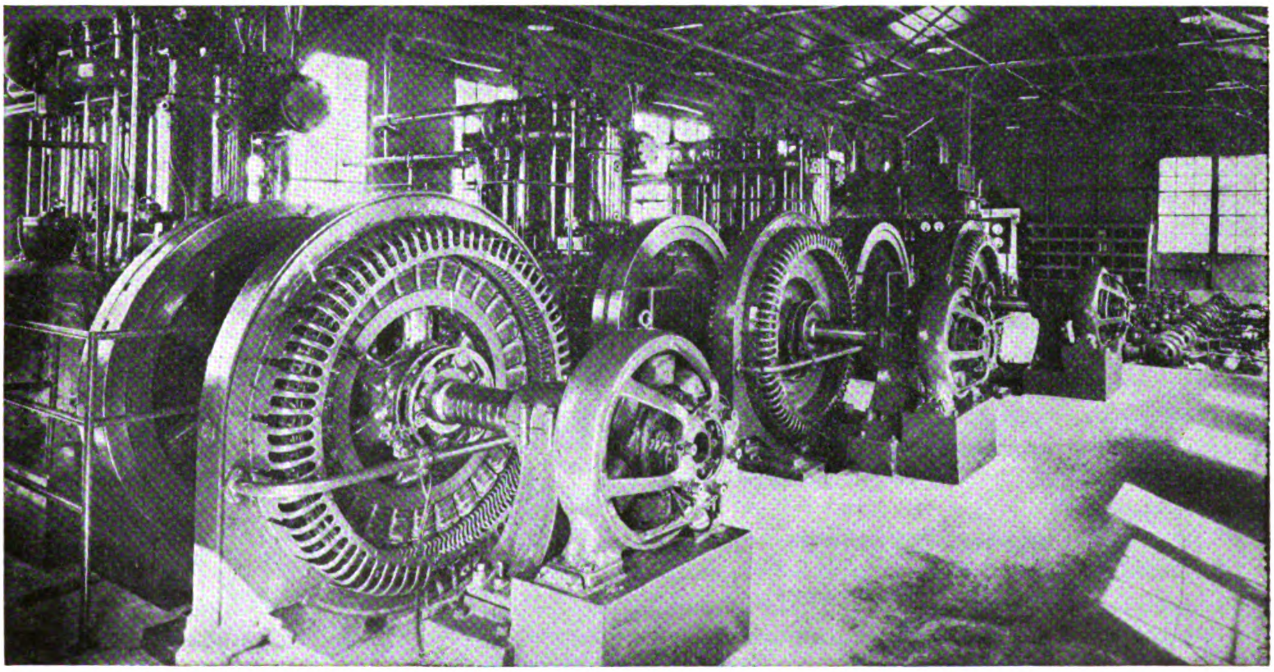
The kind of fuel used in starting the bed is unimportant just as long as the bed is well lighted throughout and is thoroughly incandescent in front of the tuyeres. In some foundries, square holes the size of two bricks placed on edge and lengthwise are made in the wall to allow a better draft on the wood or to allow the use of oil or gas burners. These holes are filled with fire brick as soon as the bed is thoroughly lighted.

With the cupola lined up approximately the same each day, the amount of coke in the bed can best be determined by measuring from the charging door. After the bed is burned through until it glows red all over and the coke shows red through all the tuyere openings, about six to ten inches of coke should be added to bring the height of bed up to approximately 20 or 30 in. above the top of the tuyeres. The tuyere openings should then be closed to prevent the bed from burning out excessively and, therefore, starting the cupola with too low a bed. In starting with a 20 to 30 in. bed, it is intended that this shall remain the height of the bed when the wind is turned off; if the bed is much over 30 in. in height, it will not be possible to get the best operating conditions.

The coke bed is of the utmost importance, and unless it is lighted properly, started at the right height, and maintained at this height throughout the entire run it will be impossible to get the best and most consistent results.

(To be continued)

Auxiliary Power Plant for a Gas Compressor Station



Generators in the Waskon Station of the United Gas Company

Effects of Short Lengths of Cable on Traveling Waves

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The investigation reported in this article is, so far as we are aware, the first really thorough one in the subject. As a consequence, the results give rise to very definite conclusions as to how cables perform under such conditions. The authors presented this information to the A.I.E.E. at the Toronto Convention this past summer.—EDITOR

THERE has been much discussion for many years concerning the effectiveness of cable in reducing the potential of incoming surges, and as a result considerable uncertainty has existed as to whether the present practises are correct with regard to methods of protection, both of the cable itself and of apparatus connected to the cable.

Recognizing this problem as being of great importance to both manufacturers and operators, a joint investigation by the General Electric Company, the Consumers Power Company, and the Detroit Edison Company was arranged late in the summer of 1929.

The General Electric Company furnished a portable impulse generator and sphere-gaps for measuring voltage. The Consumers Power Company supplied the S-19 transmission line, a portable power supply, and communication and trucking facilities. The Detroit Edison Company furnished 1000 ft. of 24,000-volt lead-sheath cable and a portable cathode-ray oscillograph.

The tests were conducted at Croton Dam (Mich.), between August 26, 1929 and November 7, 1929.

The tests dealt with the following subjects:

(1). Free waves on the transmission line.
(2). Effect of 500 ft. of cable.
(3). Effect of 1000 ft. of cable.
(4). Effect of bus between two sections of cable, each 500 ft. long.
(5). Effect of terminal conditions with 500 ft. of cable.
(6). Effect of terminal conditions with 1000 ft. of cable.
(7). Effect of grounds on sheath of the cable.
(8). Effect of lightning-arrester gap and series resistance settings.
(9). Effect of lightning arrester on the wave, on the line, and with bus between two sections of cable.

Impulse Generator

The portable impulse generator(1) used in these tests consisted of 40 banks of capacitors each having a capacity of 0.5 μf. The banks were charged in parallel to 20 kv. each and discharged in series according to the well-known Marx circuit During most of these tests the potential of the generator was reduced by disconnecting part of the banks to prevent breakdown of the cable or arcing over the potheads.

Transmission Line

The transmission line used for the tests was a section of the S-19 line of the Consumers Power Company, a description of which has already been published.(2) The location of the cable for the tests was at towers 53 to 55, a distance of 5.16 to 5.36 miles from the impulse generator, which was at the Croton end of the line. The main impulse was sent out on the middle conductor and the bottom conductor was used to carry an initiating impulse.

Strain insulators were installed on towers 53, 54, and 55 to enable a section of the cable to be inserted between sections of the line.

Oscillograph

The oscillograph used for measuring the wave-shapes was of the hot-cathode type described by George.(3) The oscillograph and its auxiliaries were easily portable, being mounted on the truck shown in Fig. 1.

Cable

The cable used for these tests consisted of 1000 ft. of lead-sheath cable having $\frac{21}{32}$-in. manila-paper insulation, and a single conductor consisting of No. 00 seventeen-strand copper. The capacity of the cable as measured with a capacity bridge was 0.03734 μf. per 1000 ft. The voltage rating of the cable was 24,000 volts.

The potheads at the cable terminals were of the type used by the Detroit Edison Company, and were installed by their cable men.

Sphere-gaps

Several sizes of sphere-gaps, ranging from 2.5 to 25-cm. diameter were used to measure crest voltage.

METHODS

Cable Divider

A cable divider similar to the one which was described by Gabor(4) was used to reduce the voltage to a safe value for use on the deflecting plates of the oscillograph. By using the cable divider, it was possible to make measurements at each end of the cable without moving the oscillograph, which was a decided advantage.

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(1) "The Portable Impulse Generator," by E. J. Wade, GENERAL ELECTRIC REVIEW, March, 1930, pp. 180-184.

(2) K. B. McEachron, J. G. Hemstreet, and W. J. Rudge: "Study of Traveling Waves on Transmission Lines with Artificial Lightning Surges." *A.I.E.E. Trans.*, Vol. 49, July, 1930.

(3) R. H. George: "A New Type of Hot Cathode Oscillograph," *A.I.E.E. Quarterly Trans.*, Vol. 48, July, 1929, p. 890.

(4) D. Gabor: "Forschungshaft de Studiengesellschaft für Hochstspannungspanlagen," *E.T.Z.*, 1 Heft., September, 1927, p. 42.

The cable divider consisted of a section of BX cable No. 14 double conductor 500 ft. in length. One conductor was tied to the sheath and grounded at each end. The other conductor was used to conduct the transient to the deflecting plates of the oscillograph. At the oscillograph end of the BX cable a resistance equal to the surge impedance of the cable was placed to ground. At the other end of the cable a high resistance was placed from the conductor to the point where the transient was to be measured. The ratio between the resistances at the two ends of the cable is the ratio of the voltage division. After making a number of comparative tests with the cable divider and capacity divider, the conclusion was reached that the cable divider reproduced the transient with sufficient accuracy, and that it was dependable in its operation. In Gabor's description of the cable divider, there was a capacity at each end of the cable. These capacities are used to suppress the 60-cycle current in the measuring circuit, but were not necessary in these tests since there was no 60-cycle voltage on the line. However, check tests were made using capacities. It was necessary to check the high-resistance water tube at the line end of the measuring cable at frequent intervals to prevent changes in the ratio due to temperature.

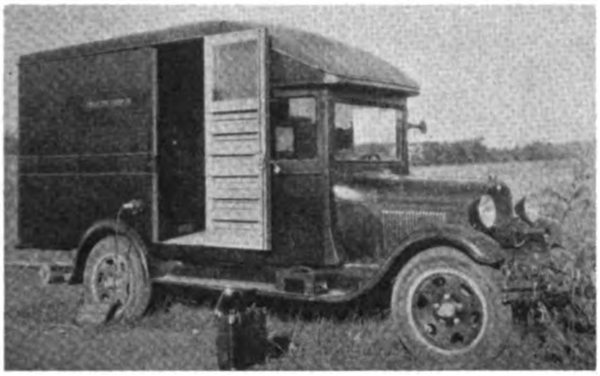


Fig. 1. The Cathode-ray Oscillograph Truck Used in Making the Tests

Determination of Time Scales and Sweeping Speeds

In order to eliminate any doubt as to timing, a 500-kc. wave was superimposed on one measured wave for each condition tested. The frequency of the oscillator was checked with a precision wave meter. This method gives a check on the sweeping speed of the oscillograph and a time scale for the transient. Usually the transients were taken, one with the 500-kc. wave superimposed, and one without, to give a continuous check on the calibration which changes somewhat with changes in vacuum. Many oscillograms in this article show the 500-kc. superimposed wave.

Sphere-gap Measurements

Sphere-gap measurements were taken for each test condition to give the crest value of the voltage. Because dirty gaps are apt to be erratic, the gaps were cleaned at frequent intervals.

Operation of the Oscillograph and Impulse Generator

Fig. 2 is a schematic diagram showing the operation of the circuits which were used with the oscillograph. The transients waves were sent out at scheduled intervals by an operator at the impulse-generator station, who closed a switch in the initiating circuit. The initiating circuit was arranged to send a 20-kv. impulse out on the line (bottom conductor) and to start the main impulse of the generator (middle conductor). There was a short delay between the 20-kv. initiating impulse and the main impulse which depended upon the time constant of the circuit coupling the two impulse circuits.

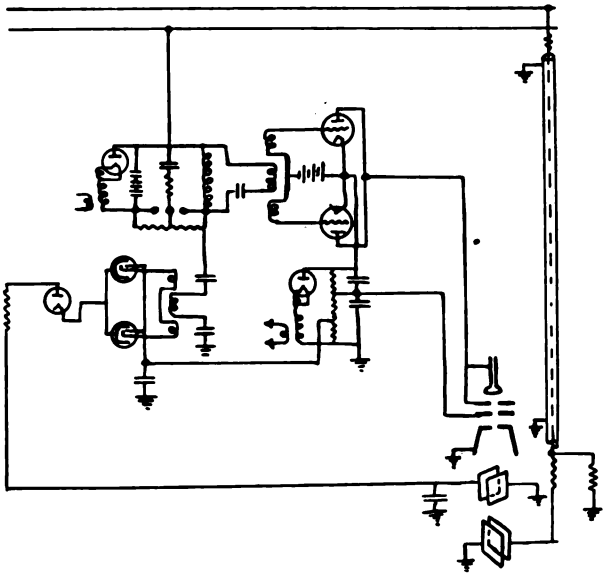


Fig. 2. Diagram of the Circuits Used in Connection with the Oscillograph

At the oscillograph the shutter was opened and the circuits energized before the main transient was due. The 20-kv. initiating impulse, arriving before the main transient, tripped a three-electrode gap, thus starting oscillations in a local circuit. The grids of the tubes in the sweeping and electron-gun circuits were coupled to the oscillating circuit so that they became energized when the local circuit began oscillating. The electron-gun circuit turned on the beam and the sweep circuit moved the beam across the film giving the time scale. The time interval between the arrival of the 20-kv. initiating impulse and the main impulse was made such that the deflection due to the main transient began after the beam had moved a short distance along the zero line. This made it possible to record the start of the transient under investigation.

Test Wave Forms

At different times as many as five different waves were used. The form of these different waves is given in Table I. All of them were of negative polarity.

PRELIMINARY MEASUREMENTS

Surge Impedance of the Line

Surge impedance measurements were made by connecting a water tube of varying resistance from line to ground and measuring the IR drop across the water tube and the voltage from the line to true ground.[2] Measurements were made both with the line continuous and line open.

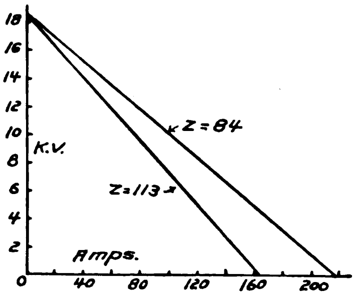


Fig. 3. Surge Impedance Measurement on 1000-ft. Cable

By this method the value for surge impedance of the middle conductor of the S-19 line used in these tests was found to be from 595 to 685 ohms. The measurements which are considered most reliable are 610 and 624 ohms. A value of 620 ohms was chosen for purposes of calculation.

Surge Impedance of the Cable

The surge impedance of the cable was determined by several methods. Each method will be described briefly and the results summarized.

The first method was similar to that used for surge impedance measurements on the transmission line. The steep wave was used and was chopped by a gap at Tower 48 which was considered to be far enough away so that reflections would not affect the result. The success of this method depends on the wave being short enough so that reflections between the two ends of the cable do not affect the measurements. In general the space wave in the cable should be less than twice the cable length although a longer wave might give the same results depending on the shape of the tail. Fig. 3 shows two values obtained, 84 and 113 ohms.

The second method is based on the reduction of voltage which occurs when a steep wave enters the cable. In Fig. 4 are shown two oscillograms, taken at Tower 53, one with the line continuous and the other with 1000 ft. of cable in circuit, but with the far end of the cable open. The effect of the cable was to reduce the wave from 92 kv. to 30 kv. on the first reflection. This was subsequently increased by successive reflections. The surge impedance of the line was determined by previous tests to be about 620 ohms. Then the surge impedance of the cable was calculated from the formula $Z_c' = E_t Z_1 2/E_o - E_t = 121$ ohms. This value of surge impedance may be considered as consisting of the actual surge impedance of the cable plus the resistance between the sheath and ground at the start, which in this case is 28 ohms. Subtracting: $Z_c = Z_c' - 28 = 93$ ohms.

The second method was also applied to measurements at the far end of the cable using sphere-gap values. It was unnecessary to take oscillograms for this case because the chopped wave which was used was short compared to the cable length, so there was no building up of the voltage by successive reflections.

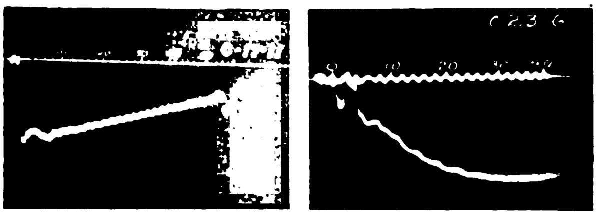
TABLE I

DATA ON WAVE FORMS USED

Designation	Voltage Crest at Tower 53	Time to Reach Crest (MS.)	Time to Decay to 50% Crest (MS.)	No. of Generator Banks Used	Series Inductance (Henrys)
Steep wave, low voltage	92	8	50	7	0
Medium wave, low voltage	120	13–15	40	10	0.002
Slow wave, low voltage	124	27	50	14	0.011
Steep wave, high voltage	225	8	15	32	0
Medium wave, high voltage	223	10	20	32	0.002

The values obtained by this method were 38 to 54 ohms. These values are probably too low due to attenuation of the voltage through the cable, and to difficulty of measuring accurately such a short wave with sphere-gaps.

The third method was to calculate the surge impedance by using the measured propagation velocity of the wave through the cable and the measured capacity in the formula: $Z = 1/(C\,v)$. The propagation velocity was calculated from the reflections on film C-20-8, Plate VI, and was found to be 61.2 per cent of the velocity of light. The capacity of the cable as measured by a bridge was 0.0373 μf. The surge impedance calculated by this method is 44.5 ohms.



Wave on continuous line at Tower 53

Wave entering 1000-ft. cable at Tower 53

Fig. 4. Oscillograms of Effect of 1000-ft. Cable on Traveling Wave

In the fourth method the impedance was calculated from the geometrical constants of the cable, which were as follows:

Diameter of conductor (No. 00)	0.413 in.
Thickness of insulation	0.656 in.
Dielectric constant (assumed)	3.0

Applying the usual formulas to these constants gives a surge impedance of 47.3 ohms.

SUMMARY OF RESULTS ON SURGE IMPEDANCE

Method	Z in Ohms
Varying terminal impedance	84 to 113
Transmitted wave, sphere-gap measured far end	38 to 54
Transmitted wave oscillogram, near end	93
Calculated, based on propagation velocity	44.5
Calculated, based on geometrical constants	47.3

These figures for the surge impedance seem to fall into two groups, one about 50, and the other approximately 100 ohms. It is believed that this discrepancy is not due entirely to errors in taking the data, but rather to factors which are not considered.

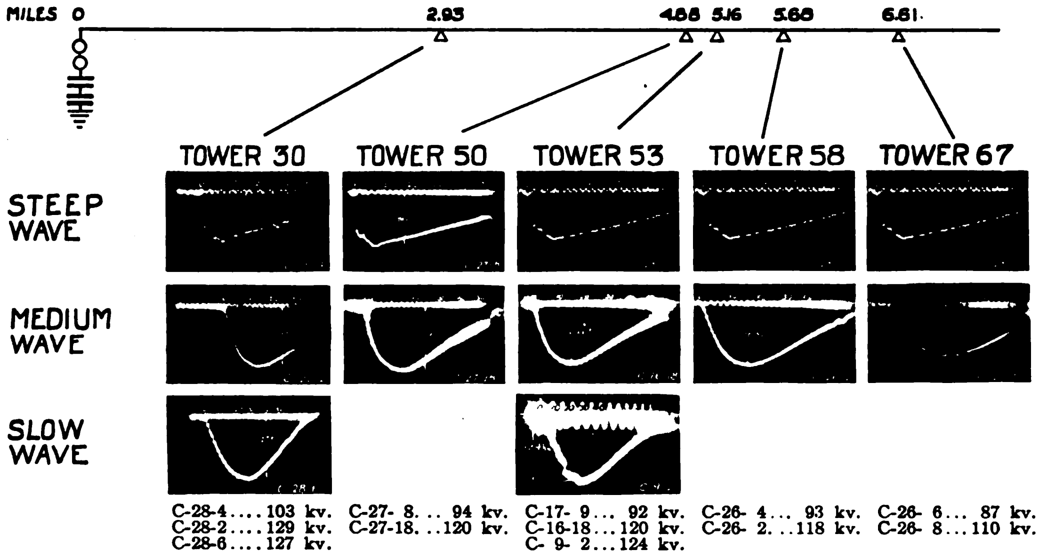


Plate I: **Shape of the Waves and Effect of Distance Traveled**

RESULTS OF TESTS

The results of the tests are shown in a series of plates on which are grouped the oscillograms dealing with each of the subjects studied. Each of the plates will be considered separately, and a summary of results given at the end of the article. On some of the plates oscillograms are repeated from other plates so that those on any one plate are complete and comparable. In all tests with the cable, the sheath was grounded at both ends unless otherwise specified.

Plate I: Shape of the Waves and Effect of Distance Traveled

The oscillograms in Plate I show the time-voltage characteristics of the three waves used during the tests as recorded by the oscillograph at several locations on the line. These curves represent free traveling waves on the line and were recorded with a continuous line from the lightning generator at Croton to the Wealthy Street Plant at Grand Rapids. No equipment other than measuring apparatus was connected to the line at the time the tests were made.

Steep Wave

From the oscillograms in Plate I it can be seen that the voltage was reduced from 103 kv. at Tower 30 to 87 kv. at Tower 67, a reduction of 14.7 per cent in 3.7 miles. The wave is made up of a very sudden rise at the start, followed by a slower rise having imposed on it an oscillation which continues until crest value is reached. After crest value, the voltage reduces along a smooth curve reaching 50 per cent of crest value in about 50 microseconds. It may be noted that the recorded wave-front is somewhat different at the various tower positions, possibly due to differences in phase relation between the fundamental wave-shape and an oscillation on the front. On the waves recorded at Towers 30 and 53, the oscillation and the fundamental appear to add together in such a manner that the initial rise of voltage is almost equal to the crest value. The oscillation apparently attenuates rapidly and is of low magnitude at Tower 67.

Measuring equipment connected to the line apparently caused a partial reflection which goes back to the generator and returns, producing the sudden rise in voltage on the tail of the waves recorded at Towers 30, 50, and 53. The time at which this rise is recorded in each case checks the calculated time for the travel of a wave from the measuring apparatus to the generator and back again.

Medium Wave

The medium wave reduces from a value of 129 kv. at Tower 30, to 110 kv. at Tower 67, a reduction of 15 per cent. This is about the same reduction as was noted with the steep wave.

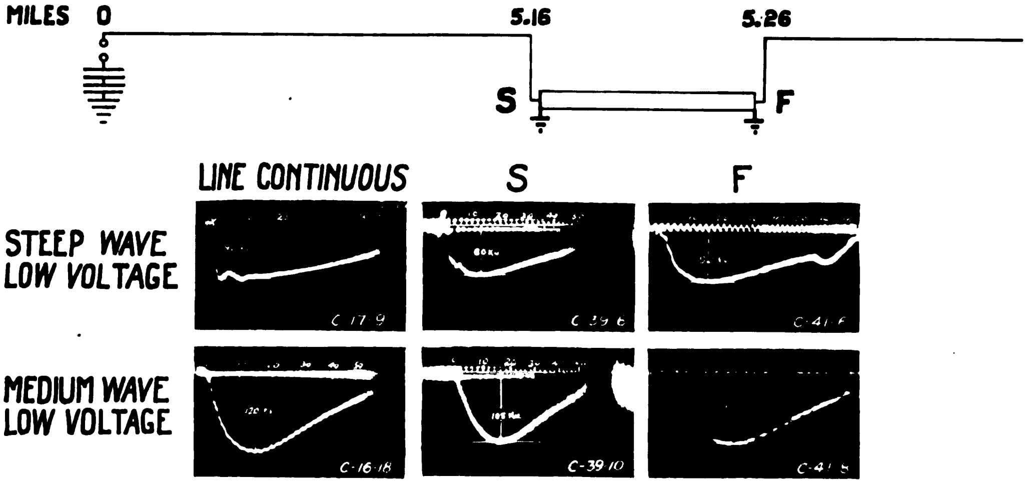
The medium wave consists of a smooth rise in voltage from zero to crest value in from 13 to 15 microseconds followed by a gradual decrease to half voltage in approximately 40 microseconds. This wave can be represented very closely by the equation: $e = 240\ \epsilon^{-0.033t} - \epsilon^{-0.134t}$ where e is in kilovolts and t in microseconds. A comparison of the oscillograms made at various locations (Plate I) shows no perceptible change in wave-shape due to travel along the line.

Slow Wave

The slow wave is smooth throughout and reaches a crest value at approximately 27 microseconds and decreases to 50 per cent crest voltage at 50 microseconds as indicated by the oscillogram taken at Tower 30. (The time scale of oscillogram C-9-2 is not reliable.) The crest voltage is 124 kv. at Tower 53.

***Plate II:* Wave Passing Through 500 Ft. of Cable**

When the wave enters a 500-ft. section of cable, the oscillograms show that the time for the voltage to rise to its crest value with the steep wave (8-microsecond front) was 12 to 15 microseconds. The crest voltage was reduced from 92 kv. to 80 kv. or about 12 per cent. The amount of reduction depends principally on the shape of the tail of the incident wave. If the voltage drops rapidly, it will limit the voltage which can be built up in the cable. The wave-front of the medium wave was slow enough so that the cable did not have any effect on its shape, although the potential was reduced from 120 kv. to 105 kv.



C-17- 9... 92 kv.
C-16-18. ..120 kv.

C-39- 6... 80 kv.
C-39-10... 105 kv.

C-41-6.... 82 kv.
C-41-8....107 kv.

Plate II: Wave Passing Through 500 ft. of Cable

***Plate III:* Wave Passing Through 1000 Ft. of Cable**

When a 1000-ft. section of cable was inserted into the line the crest voltage was reduced from 92 kv. on the free line to 70 kv. for the steep wave with the cable inserted, a reduction of 24 per cent. The wave-front was changed from 8 microseconds on the free line to 22 microseconds.

In the case of the medium wave the crest value was reduced from 120 kv. to 92 kv., a reduction of 23.3 per cent. The wave-front was changed from 15 microseconds to 25 microseconds.

The reduction in crest value of the slow wave was from 124 kv. to 102 kv., a reduction of 18 per cent.

The oscillograms taken at Towers 30 and 50 (Plate III) show the effect of the reflection from the cable on the incident wave. Of course as the oscillograph location approaches the end of the cable, the reflections approach the front of the incoming wave. Oscillogram C-29-2, taken at Tower 30, shows the reflection returning from the cable about 24 microseconds from the beginning of the incident wave.

The magnitude of the reflected wave is about 50 kv. At Tower 50 the reflected wave is nearer the crest of the incident wave.

The medium and slow waves show reflections which are similar to those of the steep wave.

Wave-shape on Line Beyond Cable

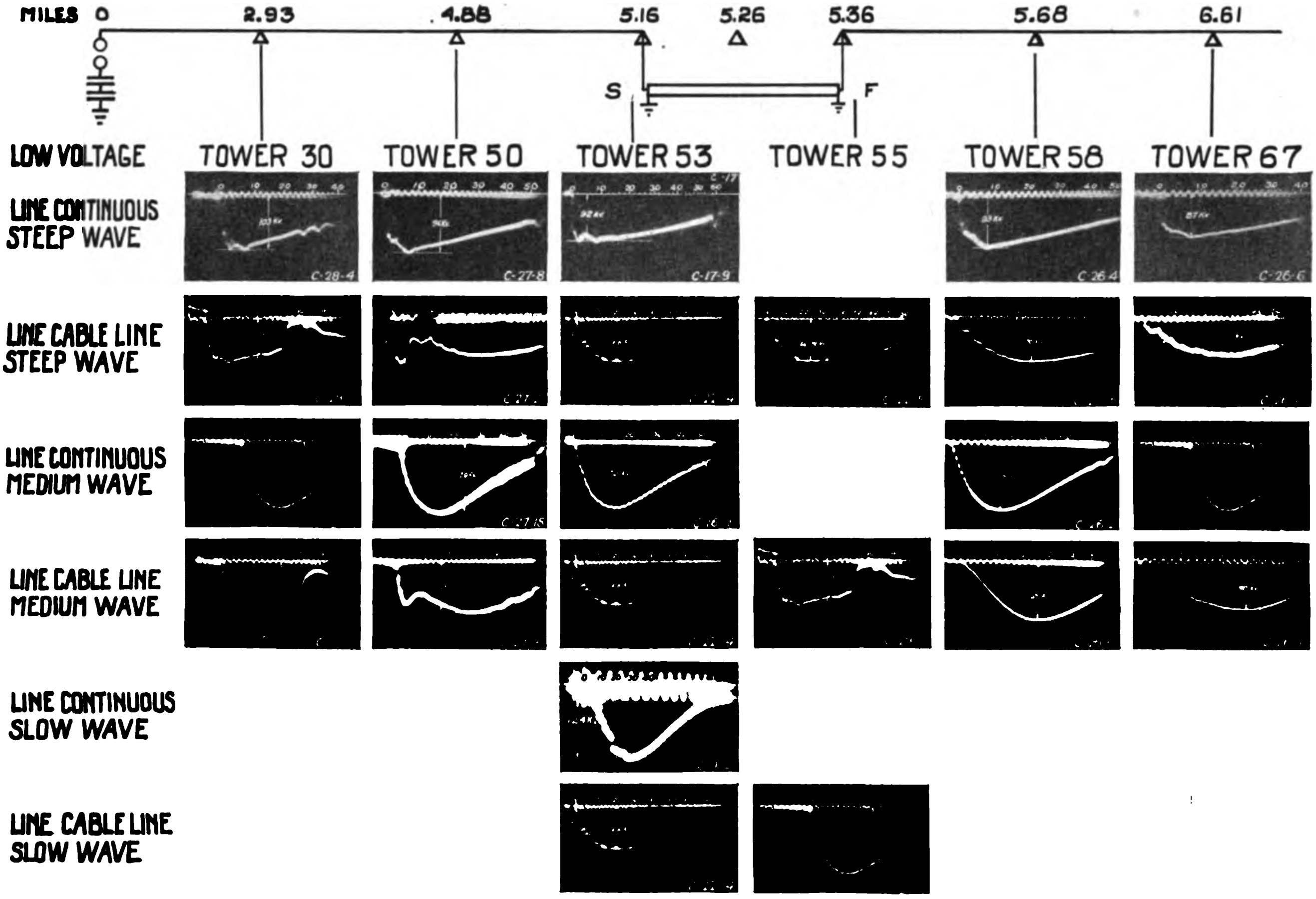
There was no distinguishable change in wave-shape along the line after the wave passed through the cable. The oscillograms taken beyond the cable at Towers 55, 58, and 67 are similar for the three waves. The rate at which the voltage builds up in the cable by successive reflections is shown most clearly by oscillogram C-25-15 at Tower 58.

***Plate IV:* Effect of Bus Between Cable Sections**

For the steep-wave low-voltage condition, a comparison of the two cases where a 1000-ft. section or two 500-ft. sections is inserted in the line, shows that with the incident wave of 92 kv. and a front of 8 microseconds, the 1000-ft. section reduces the crest voltage to 66 kv., while with the two 500-ft. sections, the crest is 71 kv. For this test the two 500-ft. sections of cable were connected together by a short jumper about 20 ft. in length. In general, the 1000-ft. section and the two 500-ft. sections have practically the same influence on the wave. The only apparent difference in the shape of the two waves is in the oscillations which appear at the front of the wave (C-40-2 and C-46-18).

Oscillogram C-41-4 which shows the wave-shape at the junction of the two cable sections, indicates that voltage conditions at this point are almost identical with the conditions at the ends of the combined sections. As may be noted, the wave at the start of the cable is practically identical with the wave at the finish of the cable on both the 1000-ft. and the two 500-ft. cable sections.

The third group of oscillograms in Plate IV were taken with a set-up consisting of two 500-ft. sections of cable connected together through a 500-ft. section of overhead line to simulate a station bus. The shape of the wave was altered at each end of the first section of cable by reflections from the second section which cut into the front of the wave and caused it to drop momentarily.



C-28-4....103 kv.	C-27- 8... 94 kv.	C-17- 9... 92 kv.		C-26- 4... 93 kv.	C-26- 6... 87 kv.
C-29-2....104 kv.	C-27- 2... 75 kv.	C-22-14... 66 kv.	C-22- 8.66-70 kv.	C-25-15... 74 kv.	C-26-12... 75 kv.
C-28-2....129 kv.	C-27-18...120 kv.	C-16-18...120 kv.		C-26- 2...118 kv.	C-26- 8...110 kv.
C-28-8....123 kv.	C-27-16... 86 kv.	C-22-16... 92 kv.	C-21-13... 87 kv.	C-25-17...100 kv.	C-26-10... 90 kv.
		C- 9- 2...124 kv.			
		C-22-18.97-103 kv.	C-22- 6...102 kv.		

Plate III: **Wave Passing Through 1000 ft. of Cable**

The crest values of voltage, 70 to 72 kv. measured at the four positions with two sections of cable and a section of bus between, have approximately the same value at all of the positions. This value of crest voltage is practically the same as that for the 1000-ft. length, which is 66 to 70 kv.

Steep Wave, High Voltage

The results in this case were similar to those for the steep wave, low-voltage. When high voltages were applied to two 500-ft. sections of cable the oscillograms showed essentially the same magnitude and wave-shape at the start, the junction, and the finish of the two cable sections. The principal difference in the wave-shape at these points was a variation in the phase relation between the fundamental and an oscillation which appears on the wave-front.

By inserting the 1000-ft. length of cable in the line, the crest voltage was reduced from 225 kv. to 120 kv., which is 53 per cent. The wave-front also was changed from 8 microseconds to 15 microseconds. This case is to be compared with the steep-wave low-voltage case. It will be noted that the change occurring in the wave-front is slightly different for the two cases. In the case of the high-voltage wave, the section at approximately crest value is very short, and the decay is very rapid. As a result, the incident voltage begins to drop before the voltage in the cable has had sufficient time to build up to its ultimate value. The low-voltage wave had a much longer duration at approximately crest value. Hence the voltage in the cable has a longer time to build up to its crest value before the incident wave begins its rapid decay. For this reason the reduction in crest voltage was greater for the high-voltage wave than for the low-voltage wave.

Medium Wave, Low Voltage

The bus between the cable sections had the same general effect as was found with the steep wave, although the reflections were not so pronounced. The relations between crest voltages at the various points were similar to those found on the steep-wave tests.

Medium Wave, High Voltage

When the medium wave, high voltage was applied to the two sections of cable with no bus between, the wave-front of the resultant wave had an 18-microsecond front as compared with 10 microseconds for the incident wave. The crest voltage was reduced from 233 kv. to 146 kv., a reduction of 37.2 per cent.

Line to Cable tu Line, and Line to Cable (*Low Voltage*)

Comparing the conditions where a line is open to the case where the line is connected to a cable, the far end of the cable being open, we find that the cable has reduced the crest voltage from 170 kv. to 132 kv., a reduction of 22.3 per cent. By having the cable inserted between two sections of line the voltage is reduced to 80 kv.

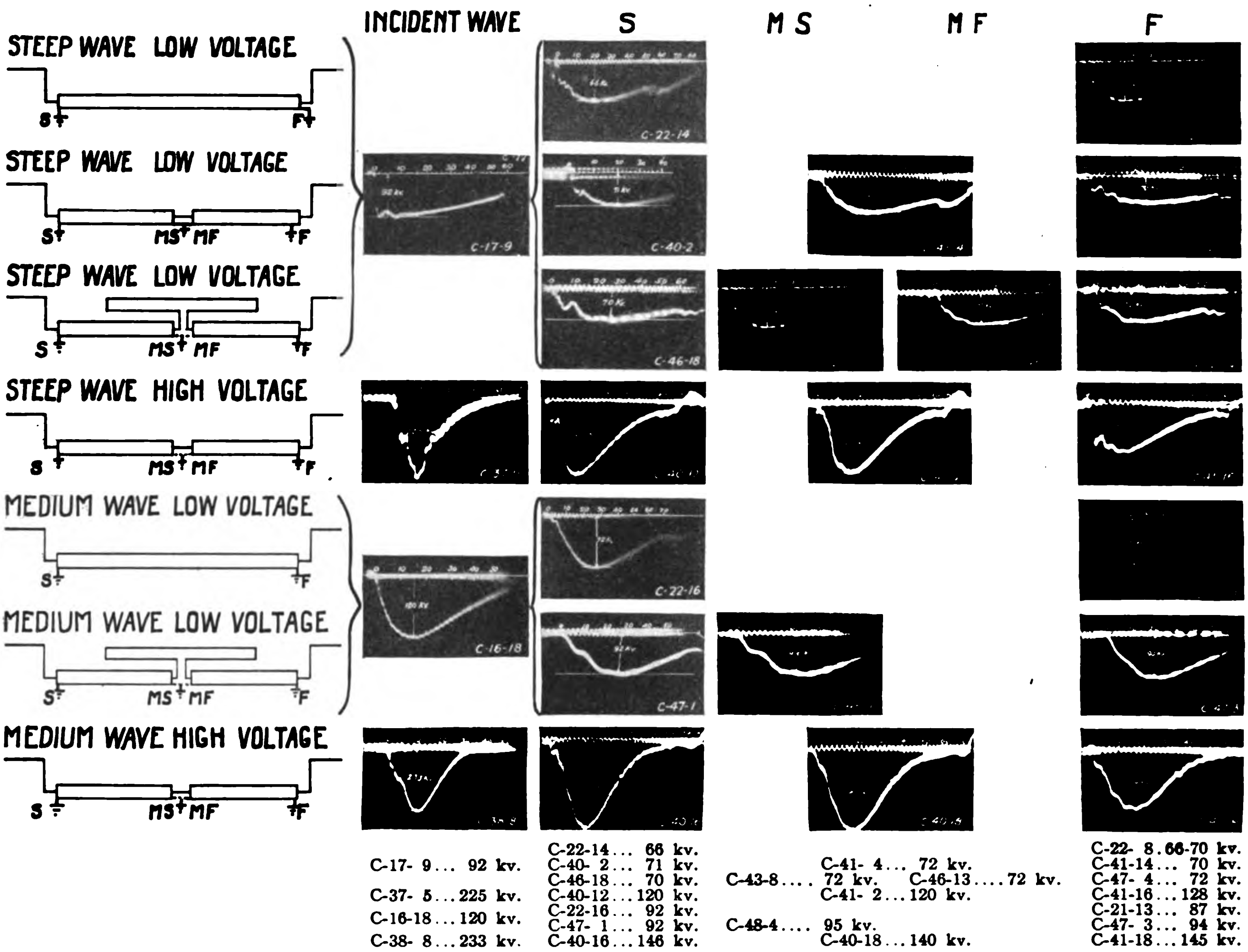


Plate IV: **Effect of Bus Between Cable Sections**

Plate V: **Effect of Terminal Conditions**

In Plate V oscillograms are shown for a variety of terminal conditions, with and without the 500-ft. length of cable in circuit.

With line open and with it connected to ground, the reflections both with the steep wave and with the medium wave are clearly defined. With the line open the reflection adds, while with the line closed to ground the reflection subtracts.

Ground at "F"

The ground at *F* on the cable conductor holds the voltage at both ends to a low value. With the steep wave, the initial rise in voltage (13 kv.) and two reflections were measured.

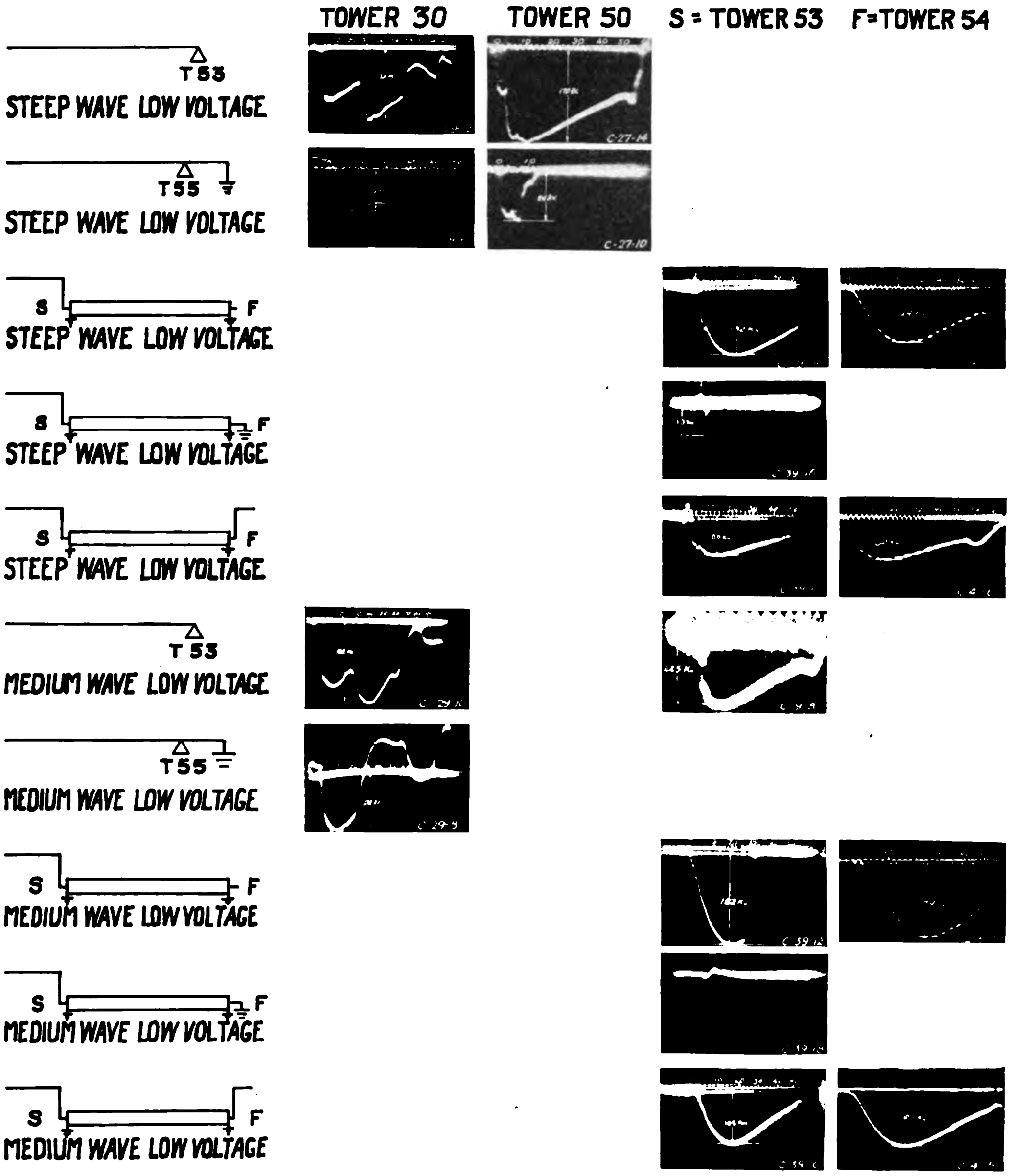
The medium wave tests show the voltage of the line-cable condition 70 per cent higher than that of the line-cable-line condition. Oscillogram C-39-12 shows a chopped wave resulting from an accidental arc-over of one of the leads to the cable pothead.

Plate VI: **Terminal Conditions with 1000-ft. Cable**

Oscillogram C-28-18 with the steep wave shows the incident wave and the reflections at Tower 30, which was about 2.3 miles from the start of the cable. For the first 25 microseconds the wave was unaffected by reflections and corresponds to the incident wave. At 25 microseconds a negative reflection with respect to the incident wave comes back as a result of the incident wave passing into the cable which is of lower surge impedance than that of the line. The voltage then remains almost constant for about three microseconds, which represents the time required for the wave to pass through the cable and be reflected to double voltage. The sudden rise in voltage at 33 microseconds is due to the first reflection from the far end of the cable. The voltage then continues to rise by steps as the wave reflects back and forth in the cable, approaching its maximum value. The second of this series of steps occurs at 37 microseconds. The oscillograms taken at Towers 50, 53, and 55 show the same effect as that shown in the oscillograms previously considered, the only difference being in the time relation between the incident wave and the reflectons.

It may be seen that the voltage at the far end of the cable for the line-cable condition was 110 kv. or 120 per cent of the incident wave, which was 92 kv., as seen from Plate I. The voltage did not rise to twice the value of the incident wave because the incident wave was of relatively short length. The decay of voltage on the tail of the wave was at approximately the same rate as the build-up of voltage through the cable.

The medium wave and the slow wave which are reproduced here showed similar behavior except that the reflections are not as well defined.



C-29-12 . . . 138 kv.
C-29- 6 . . . 103 kv.

C-29-10 . . . 162 kv.
C-29- 8 . . . 130 kv.

C-27-14 . . . 170 kv.
C-27-10 . . . 86 kv.

C-39-14 . . . 132 kv.
C-39-16 . . . 13 kv.
C-39- 6 . . . 80 kv.
C- 9- 8 . . . 225 kv.

C-39-12 . . . 182 kv.
C-39-18 . . .
C-39-10 . . . 105 kv.

C-41-12 . . . 129 kv.

C-41- 6 . . . 82 kv.

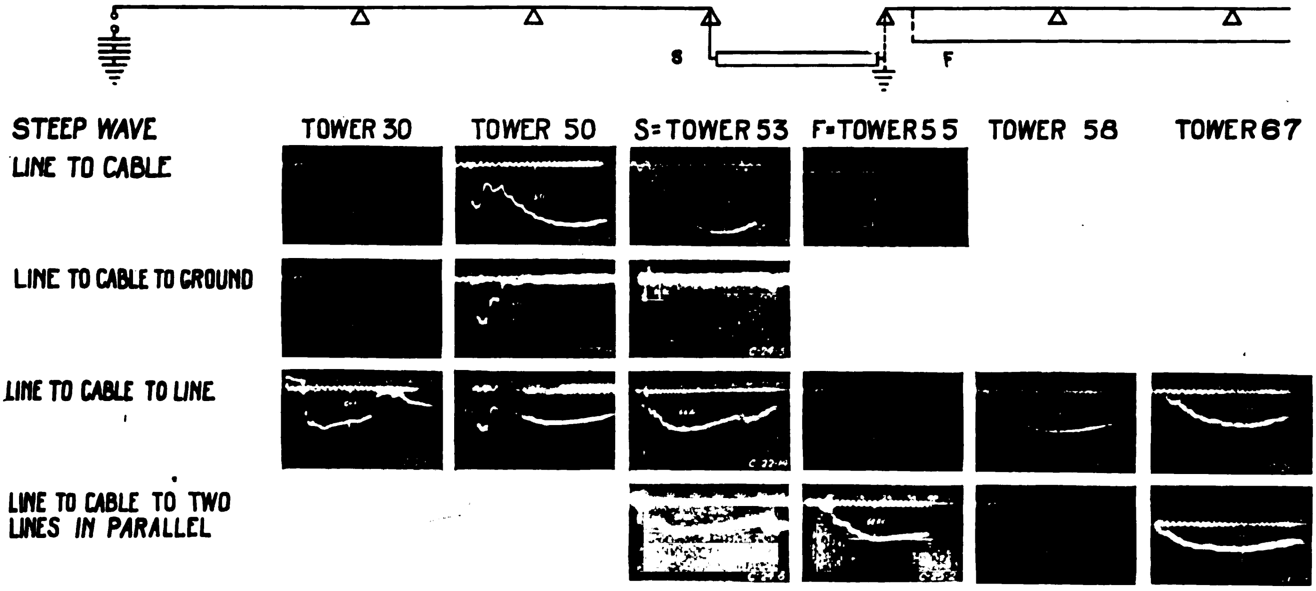
C-41-10 . . . 179 kv.

C-41- 8 . . . 107 kv.

Plate V: **Effect of Terminal Conditions**

Line to Cable to Line

The oscillograms shown in the line-cable-line condition are similar to those appearing in the line-cable condition except that the reflections at the far end of the cable are less, owing to the fact that a portion of the wave is transmitted onto the line. This results in a decrease in voltage as may be seen by a comparison of the line to cable and line-cable-line conditions at Tower 55 (steep wave) which shows the voltage to be 110 kv. for the line-cable condition as compared to 66-70 kv. for the line-cable-line condition, a reduction of 40 per cent. Comparison of corresponding oscillograms for the medium and slow waves shows similar behavior, the reduction being 40 per cent for the medium wave, and 39 per cent for the slow wave.



C-28-18...104 kv.	C-27-6....115 kv.	C-15-18...112 kv.	C-20-8....110 kv.		
C-28-16...105 kv.	C-27-4.... 76 kv.	C-24- 3... 26 kv.			
C-29- 2...104 kv.	C-27-2.... 75 kv.	C-22-14... 66 kv.	C-22-8..66-70 kv.	C-25-15... 74 kv.	C-26-12....75 kv.
		C-24- 6... 51 kv.	C-25-2.... 60 kv.	C-25-13....61 kv.	C-26-14....57 kv.

Plate VI: **Terminal Conditions with 1000-ft. Cable**

Waves measured at Towers 58 and 67, beyond the cable, give essentially the same wave-shapes as those at the far end of the cable.

It may be seen at the start end of the cable that the steep wave reaches its crest in 25 to 30 microseconds for the line-cable-line condition.

Line to Cable to Ground

Waves recorded for the line to cable to ground condition are identical to those of the line to cable condition up to the time of the first reflection from the far end of the cable. This reflection comes back negative (with respect to the incident wave) instead of positive. The result was an oscillation in the cable as is shown on oscillogram C-24-3. The first rise in voltage goes to 26 kv. followed by seven reflections which are readable on the original film.

Line to Cable to Two Lines in Parallel

The difference in shape of the wave with two lines in parallel when compared to one line is too small to be detected on the oscillograms. The voltage was lowered from 70 kv. to 60 kv. (Plate VI) which is a reduction of 14 per cent when measured at *F*.

Plate VII: **Effect of Grounds on Cable Sheath—Voltage Between Conductor and Ground**

The only condition where the variation in the grounding of the sheath had any effect was with the steep wave, line-cable-line and line-cable conditions. Grounding at the start of the cable, only, gave the same result as grounds at both the start and finish of the cable; whereas grounding at the finish, only, gave a much higher initial rise in the voltage at the beginning of the wave. The final wave-shape was the same as in the other conditions of grounding.

Sheath to Ground Voltage

With the sheath grounded at *F* and *S* or at *S* only, the initial voltage rise on the sheath measured at *S* was practically the same when a steep wave was used. The tail of the wave was lower and the voltage dropped faster with both ends grounded than with a ground at *S* only. This was due to the lower resistance of the two cable sheath grounds in parallel. The voltage which appears at *S*, when *S* is grounded, is due to ground resistance.

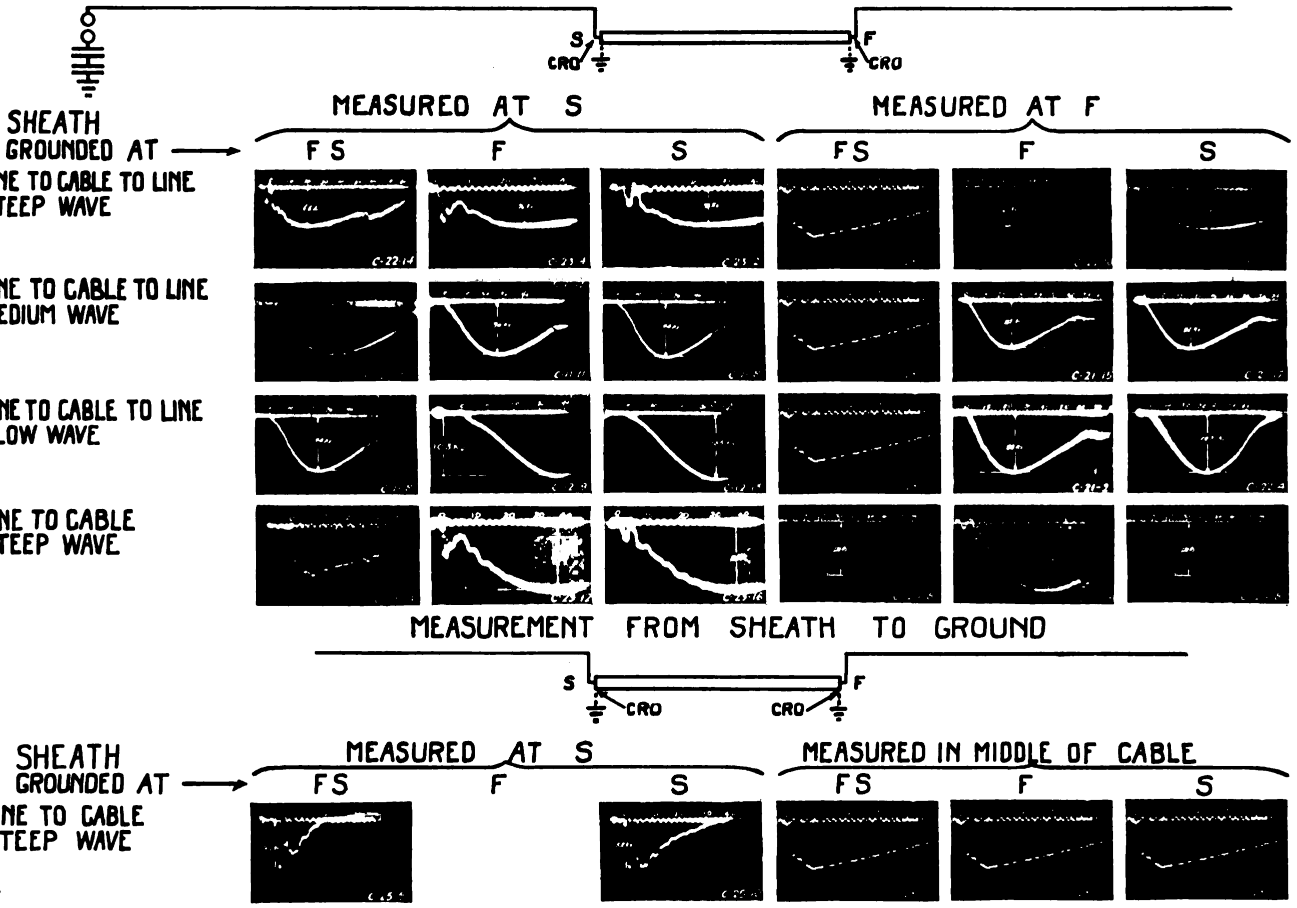
Measurements made at the middle of the sheath to ground show very little difference in the voltage to ground when *F* and *S* are both grounded over the case where *S* only is grounded. The measured voltages were essentially the same, being 13 and 14 kv.

With a ground at *F* only, the initial voltage rise was 40 kv. However, the duration of the wave was nearly the same as for the grounding conditions previously treated.

It may be noted that the duration of the wave when measured at the middle of the cable sheath was much shorter than when measured at *S*. The measurements made in the middle of the cable were made with a capacity divider.

Plate VIII: Lightning Arresters

In these tests the lightning arresters were composed of a gap in series with a water-tube resistance which was connected between the cable conductor and the sheath. Both the gap settings and the resistances were varied during these tests, thus making calculations possible for an arrester having any value of resistance.



C-22-14... 66 kv.	C-23- 4... 70 kv.	C-23- 2... 70 kv.	C-22- 8. 66-70 kv.	C-22-10... 69 kv.	C-22-12... 67 kv.
C-22-16... 92 kv.	C-11-11... 90 kv.	C-11- 8... 94 kv.	C-21-13... 87 kv.	C-21-15... 87 kv.	C-21-17... 92 kv.
C-22-18 97-103 kv.	C-12- 9...103 kv.	C-12-13...105 kv.	C-22- 6...102 kv.	C-21- 2... 90 kv.	C-22- 4...103 kv.
C-15- 8...112 kv.	C-23-12...110 kv.	C-23-16...105 kv.	C-20- 8...110 kv.	C-20-10...110 kv.	C-20-12...109 kv.
C-25- 8... 8.2 kv.		C-25-10... 8.2 kv.	C-23- 8... 14 kv.	C-23-10... 40 kv.	C-23-14... 13 kv.

Plate VII: **Effect of Grounds on Cable Sheath**

Resistance

When a gap with no series resistance was placed between the conductor and sheath, spark-over of the gap started an oscillation in the cable, the frequency of which was determined by the constants of the cable (C-23-18).

With the arrester at *F* and measurements at *S*, the reduction in voltage due to the arrester takes place three microseconds later than for the case where the arrester was at *S*. (C-19-2 and 12.)

With the arrester at *S*, the wave which passed the arrester was reflected when it reached the open end of the cable, as is shown in C-20-16. The increase in voltage over the gap setting was 15 kv.

Plate IX: Lightning Arresters, Wave Along Line

It will be seen that the reflections with the arrester are intermediate between the conditions with no arrester and with a low resistance ground at the cable end. The degree of similarity with one or the other condition depends on the arrester resistance.

Condition with Bus Between Cables

For this condition the voltage at both ends of the first section of cable was six to seven kv. higher than the arrester gap setting; while the voltage at the start of the second section (at the arrester location), was practically the same as the gap setting. This increase in voltage at points distant from the arrester can be explained for the first section as due to the increase in voltage taking place before the wave of reduction returns from the arrester.

THEORETICAL CONSIDERATION

Calculation of the Wave Shape

To calculate the effect that the 1000-ft. length of cable would have on one of the waves and to check the actual oscillograms taken, the following graphical method was used:

The equations for the waves at a transition point are:

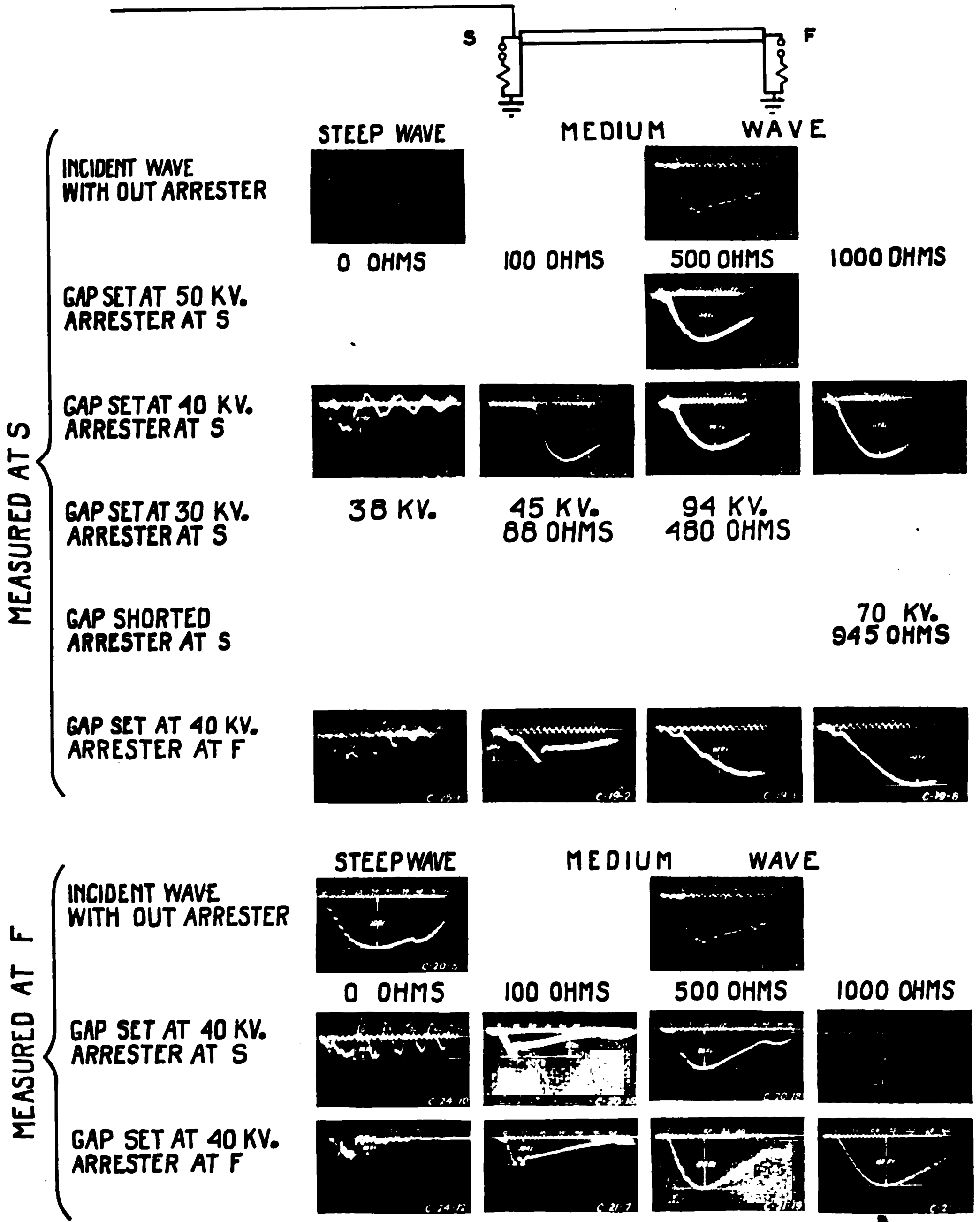
Incident wave: e = value at time t.

Reflected wave: $$e' = e\,\frac{1-\dfrac{Z_1}{Z_2}}{1+\dfrac{Z_1}{Z_2}}$$

Transmitted wave: $$e'' = e\,\frac{2}{1+\dfrac{Z_1}{Z_2}}$$

The impedance of the transmission line is taken as approximately 620 ohms, and that of the cable as 103 ohms or 1/6 that of the line, which gives:

$e' = -5/7\,e$ for Line to Cable $e'' = 2/7\,e$ for Line to Cable
$e' = 5/7\,e$ for Cable to Line $e'' = 1\,5/7\,e$ for Cable to Line



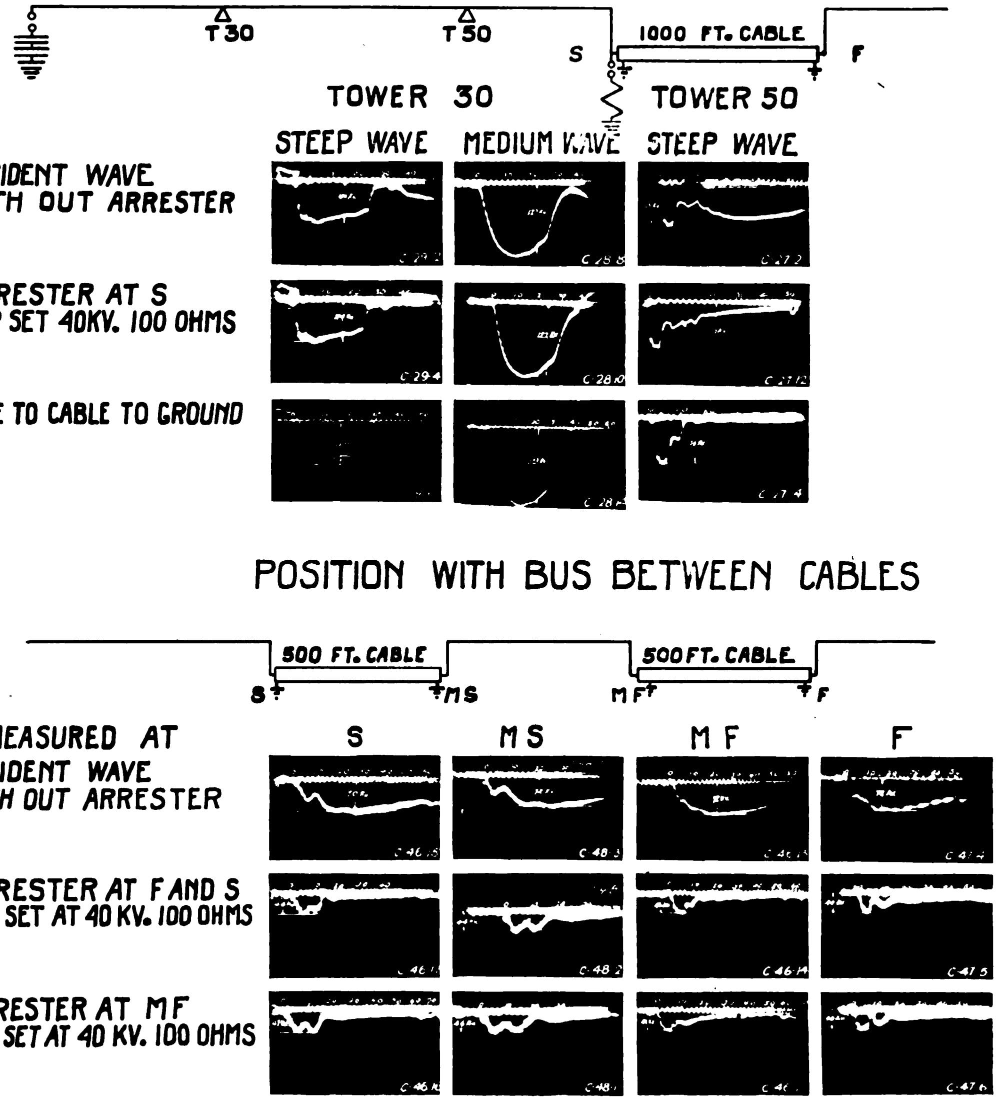
C-15- 8...112 kv.		C-19-10...147 kv.	
		C-19-18... 94 kv.	
C-23-18... 47 kv.	C-19-12... 45 kv.	C-19-14... 94 kv.	C-19-16...117 kv.
C-25- 6... 52 kv.	C-19- 2... 60 kv.	C-19- 6... 95 kv.	C-19- 8...110 kv.
C-20- 8...110 kv.		C-20-14...144 kv.	
C-24-10... 58 kv.	C-20-16... 55 kv.	C-20-18... 90 kv.	C-21- 2... 90 kv.
C-24-12... 45 kv.	C-21- 7... 50 kv.	C-21-19... 89 kv.	C-21-11...109 kv.

Plate VIII: **Lightning Arresters**

The steep wave as shown by oscillogram C-27-8, Plate I, is approximately shown by a straight line from zero to 70 per cent in one microsecond, a straight line from 70 per cent to 100 per cent in six microseconds, and from 100 per cent to 68 per cent in 23 microseconds. Being measured on a continuous line and neglecting attenuation, this is also the space wave incident to the cable.

The length of time for a point on the wave to travel from one end of the cable to the other is 1⅔ microseconds in space. For the transmission line 1000 ft. is represented by one microsecond. In Fig. 5 space waves are shown for various intervals in microseconds after the incident wave has reached the cable, each interval being chosen so that sudden changes at places to be measured will show in the final curves. Each space wave is made up graphically by drawing the reflected waves with the transmitted wave and adding them together. This becomes a very laborious process after a few reflections have passed back and forth through the cable.

From these space waves, curves showing voltage with time can be taken at any point on the line. Fig. 6 shows such curves for positions at the start end of the cable *S*, the finish end of the cable *F*, and for Tower 50. Comparing these curves with the actual oscillograms C-22-14, C-22-8, and C-27-2 as shown on Plate III, the shapes of the waves agree. C-25-15 Plate III, is probably a better picture of what happens at *F*, being only 1500 ft. from *F* and more nearly agrees with the calculated curves. The reduction in voltage shows from 24 per cent to 28 per cent for the oscillograms and 12 per cent for the calculated values. The time for the voltages to reach crest value agrees.



C-29- 2 . . . 104 kv.	C-28- 8 . . . 123 kv.	C-27- 2 . . . . 75 kv.	
C-29- 4 . . . 104 kv.	C-28-10 . . . 122 kv.	C-27-12 . . . . 71 kv.	
C-28-16 . . . 105 kv.	C-28-14 . . . 123 kv.	C-27- 4 . . . . 76 kv.	
C-46-18 . . . 70 kv.	C-48-3 . . . . . 72 kv.	C-46-13 . . . . 72 kv.	C-47-4 . . . . . 72 kv.
C-46-17 . . . . 40 kv.	C-48-2 . . . . . 44 kv.	C-46-14 . . . . 46 kv.	C-47-5 . . . . . 40 kv.
C-46-16 . . . . 47 kv.	C-48-1 . . . . . 46 kv.	C-46-15 . . . . 41 kv.	C-47-6 . . . . . 40 kv.

Plate IX: **Lightning Arresters, Wave Along Line**

SUMMARY OF RESULTS AND CONCLUSIONS

(1). There was no appreciable change in wave-shape with distance for the section of line used. The crest voltages of the waves were close to the critical corona voltage of the line. Hence no great attenuation of crest voltage appears, and very little change in the wave-front. The distance covered by measurement with sphere-gaps and oscillograms was 3.7 miles.

(2). Attenuation of crest voltage was small. In traveling 3.69 miles the steep wave was reduced 15.5 per cent, and the medium wave was reduced 14.7 per cent.

(3). High-frequency oscillations which appear on the front of a steep wave are damped as the wave travels along the line.

(4). A wave having a front whose length is short, compared to the time required for the voltage to build up in the cable, will be less steep after passing through a cable.

(5). The amount of change in wave-front for a wave passing through a cable will depend on:

(*a*). The steepness of the wave-front.

(*b*). The length of the crest or near crest of the wave.

(*c*). The length of the cable.

(*d*). The values of surge impedance for line and cable.

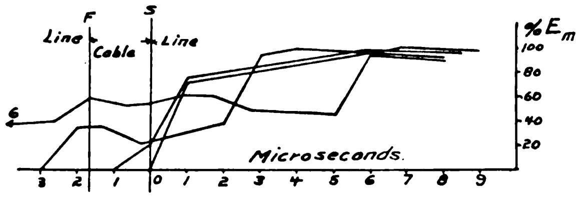


Fig. 5. Graphical Solution of Traveling Wave-shape

For a 500-ft. cable, the wave which rises in 8 microseconds and which decays to half value in 50 microseconds, an 8-50 wave, was changed from an 8-microsecond front to a 12-microsecond front when entering the cable from the line.

For a 1000-ft. cable, the 8-50 wave was changed from an 8-microsecond front to a 24-microsecond front when entering the cable from the line.

(6). A wave passing through a section of cable will have its crest value reduced unless the wave has a flat top long enough to cover the time required for the cable voltage to build up by reflections to practically the crest value of the incident wave.

For a 500-ft. section of cable, the crest voltage was reduced 10.8 per cent for both the steep wave and the medium wave.

For a 1000-ft. cable, the crest voltage was reduced 24 per cent for the steep wave, 23.3 per cent for the medium wave, and 17 per cent for the slow wave.

(7). The propagation velocity was found to be 600 ft. per microsecond in the cable.

(8). When a wave passed into the cable, the initial transmitted wave was approximately 30 per cent of the incident wave. This value is dependent on the surge impedance of both line and cable.

(9). The two 500-ft. lengths of cable with a short connection between them had practically the same influence on a wave as the single 1000-ft. length of cable.

(10). By inserting a 500-ft. connection between the two sections of cable an oscillation was introduced on the front of the wave passing through the cables. The crest voltages were unchanged by this addition.

(11). A short section of cable acts like a concentrated capacity at the open end of a line or at an intermediate point in a line, provided the length of the wave-front is long when compared to the time required for the wave to be reflected through the cable. Such a cable or capacitor does not reduce the surge voltage at the connected point if the incident wave has a long flat top.

(12). Short lengths of cable cannot be regarded as protective devices for the reduction of overvoltage surges with long flat tops such as often occur in service.

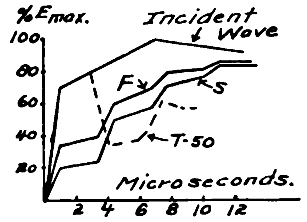


Fig. 6. Graphical Solution of Traveling Wave-shape

(13). Grounding the sheath of the cable at the start *S* gives the same result as grounding at both ends. When the sheath was grounded at the far end of the cable only, the entering wave, measured to ground, had a higher value. This higher voltage was due to the potential between sheath and ground when the sheath was not connected to ground at the start of the cable. After a few reflections through the cable, the wave assumes the same shape whether the cable is grounded at one end or at both ends. This effect is dependent upon the wave-shape and the length of the cable.

(14). A traveling wave in a section of cable may be calculated graphically, if the incident wave is given, and the calculated wave will check the measured waves closely.

(15). Arrester operation for any type of arrester may be calculated from the volt-ampere curves obtained under similar conditions.

(16). The increase in voltage at the other end of the cable from the arrester location was about 15 kv. This increase depends upon the steepness of the wave and the length of the cable, and may be estimated for any specific case.

The writers wish to express their appreciation to Messrs. E. J. Wade, W. J. Rudge, F. Osgerby, and J. R. Eaton, of the coöperating companies who conducted the field tests and furnished valuable assistance in preparing this article.

The Elements of Circular Corrugations

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CIRCULAR corrugations, employed frequently in manufactured products and in other structures, have become so familiar that a definition of them may be dispensed with here. Suffice it to state, however, that the corrugations treated in this article will be strictly of those composed entirely of circular arcs, tangent to each other.

Referring to Fig. 1, which represents a portion of the longitudinal section of a series of corrugations, let R_1 and R_2 be the radii of "crest" and "trough" arcs, respectively; h, the depth of the corrugations; and P, their pitch or period. The ratio,

$$r=\frac{h}{R_1+R_2}$$

which we will call *profile index* for convenience of future reference, is related to P and h through the equations

$$P=2h\sqrt{\frac{2}{r}-1} \qquad (1)$$

and

$$\left.\begin{aligned} r&=\frac{2}{1+\frac{1}{4}\left(\frac{1}{e}\right)^2}\\ \text{where}\quad e&=\frac{h}{P}\end{aligned}\right\} \qquad (2)$$

Curve (B) in Fig. 2 is plotted for values of r against values of e. It will give results sufficiently accurate for preliminary determinations of r, if h and P are the starting data.

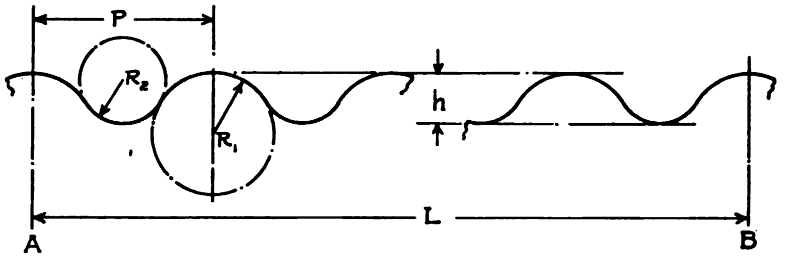

Fig. 1

Developed Length

Referring again to Fig. 1, the *developed length* D, of the circular corrugations between two vertical planes, A and B, passing through centers of "trough" or "crest" arcs, and separated by the distance L, is

$$\left.\begin{aligned} D&=KL\\ \text{where}\quad K&=\frac{\sin^{-1}\sqrt{2r-r^2}}{\sqrt{2r-r^2}}\end{aligned}\right\} \qquad (3)$$

Curve (A) in Fig. 2, plotted directly for values of K against values of the profile index r, and also against values of e through Curve (B), is intended to facilitate the determination of developed lengths. It is to be noted that the values of r in the graph are limited to the range 0 to 1; that is, from values corresponding to no corrugations at all, to those of corrugations formed by semicircles. This, of course, agrees with the limitations of molded corrugation. Theoretically, however, it is possible to increase this range to the geometrical limit 2.

The accuracy derived from the graph in Fig. 2 is sufficient for ordinary work; for it is clear that the refinement of direct computation of K by means of the formulas, in dealing with ordinary specific cases, will be futile, because distortion of the corrugations is likely somewhat to alter the intended developed length; and also because the length in practice where corrugations are used is not ordinarily a matter of rigorous exactitude.

Example 1. A problem likely to arise in actual design is the following: Given the required total length between two planes, A and B, it is desired to determine the dimensions of the corrugations.

Suppose that this length is 28 in. minimum, and the distance L between planes A and B is 21 in., approximately. The first item required is the profile index. From Equation (3) we have $K=D/L=28/21=1.33$, approx. Curve (A) in Fig. 2 gives at once $r=0.71$ approx., corresponding to $K=1.33$. Then,

$$\frac{h}{R_1+R_2}=0.71$$

Geometrically, there is an infinite degree of freedom in choosing the correlated values of h, R_1, and R_2. For our purpose, let us make $R_1=0.375$ in., and $R_2=0.5$ in. These values give, for the depth of the corrugations, $h = 0.71\ (0.375 + 0.5) = 0.621$ inches. From Equation (1) we get

$$P=2\times0.621\sqrt{\frac{2}{0.71}-1}=1.675 \text{ inches}$$

The number of corrugations will evidently be $21/1.675 = 12.5$ approx. Clearly, one of the planes A or B will cut a "crest" and the other a "trough." If the number of corrugations is to be a whole number, 13 corrugations may be used, in which case L will be increased to $13 \times 1.675 = 21.76$ in., approx., and D will increase to $1.33 \times 21.76 = 28.94$ inches, approx.

Example 2. It might be necessary to know the length over a corrugation whose "trough" and "crest" radii are not easily determined by direct measurement. To do this, we merely ignore these radii and simply measure the depth h (using a depth gauge, or straight edge and scale), the length L of the corrugation, and count the number n or corrugations. Then we proceed as in the following concrete example:

Let $h = 0.76$ in., $L = 32$ in., and $n = 16$. First we find the pitch: $P = L/n = 32/16 = 2$; then determine $e = h/P = 0.76/2 = 0.38$. By using the graph in Fig. 2, we find the value of K to be 1.35, corresponding to $e = 0.38$. Finally, the developed length sought will be $D = KL = 1.35 \times 32 = 43$ in., approx.

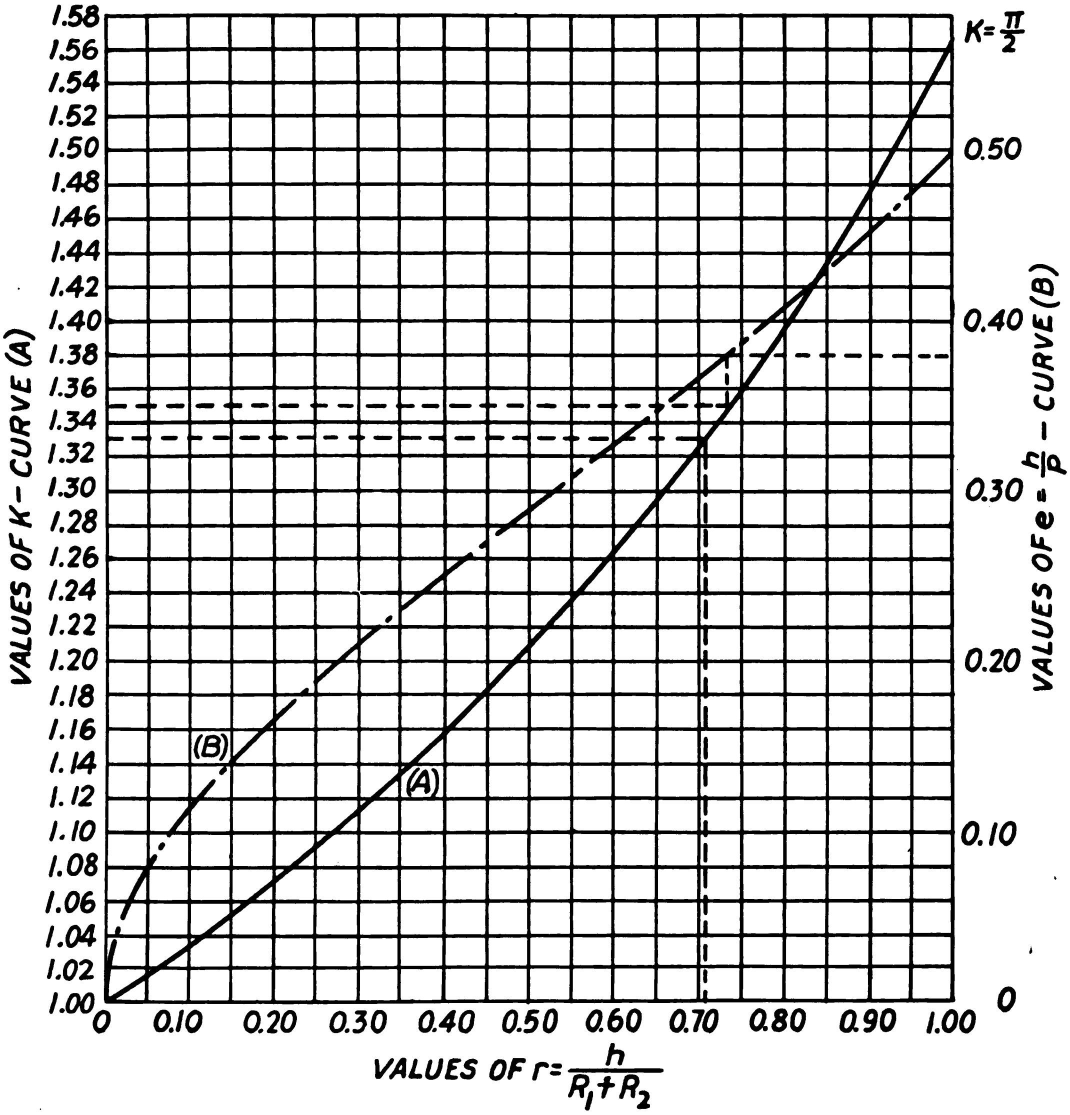

Fig. 2

A Geometrical Concept of K

Let us examine the relation

$$K = \frac{\sin^{-1}\sqrt{2r - r^2}}{\sqrt{2r - r^2}}$$

The denominator of the fraction readily suggests the equation of the circle of unit radius, with its center on the x-axis and its circumference at the origin, $r = x$ being the argument. The numerator is the length of the arc described by a moving point B: (x, y) reckoned from the origin. Referring to Fig. 3 we have, therefore,

$$OA = r$$

and

$$K = \frac{\text{arc } OSB}{AB} = \frac{\phi}{\sin\phi}$$

Derivation

Let Fig. 4 represent an exact semi-cycle of the corrugations shown in Fig. 1. By the geometry of the figure

$$h = (1 - \cos\phi)\,(R_1 + R_2) \qquad (4)$$

from which the profile index is established thus:

$$r=\frac{h}{R_1+R_2}=1-\cos\phi \qquad (5)$$

From Equation (5) we get

$$\cos\phi=1-r \qquad (6)$$

Recurring again to the geometry of the figure we make

$$\frac{1}{2}P=\sin\phi\,(R_1+R_2)=\sqrt{1-\cos^2\phi}\,(R_1+R_2) \qquad (7)$$

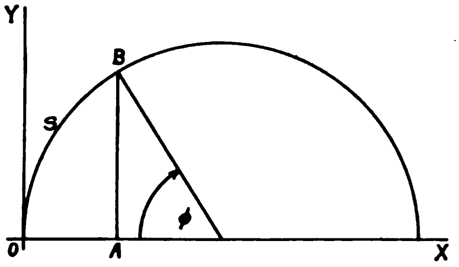

Fig. 3

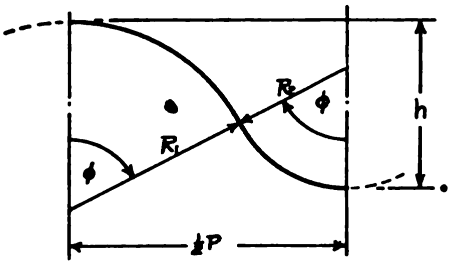

Fig. 4

Dividing Equation (7) by Equation (4) we obtain

$$\frac{\frac{1}{2}P}{h}=\frac{R_1+R_2}{h}\sqrt{1-\cos^2\phi}$$

which, upon further substitution of values given by Equations (5) and (6), and solving for P, is transformed into Equation (1):

$$P=2h\sqrt{\frac{2}{r}-1}$$

whence Equation (2) is readily derived.

From Equation (5) we obtain the angle

$$\phi=\cos^{-1}(1-r)=\sin^{-1}\sqrt{2r-r^2} \qquad (8)$$

restricting ourselves to the principal value of this inverse trigonometric function. Now, let d be the developed length of the semi-cycle of Fig. 4, so that the total developed length of a series of n corrugations or cycles between planes A and B in Fig. 1 will be

$$D=2nd$$

But

$$n=\frac{L}{P},\ \text{and}$$

$$d=(R_1+R_2)\phi=(R_1+R_2)\sin^{-1}\sqrt{2r-r^2},\ \text{by Equation (8);}$$

therefore

$$D=2\frac{L}{P}(R_1+R_2)\sin^{-1}\sqrt{2r-r^2} \qquad (9)$$

Putting Equation (1) in the form

$$P=2\frac{h}{r}\sqrt{2r-r^2}$$

and substituting in Equation (9), we get

$$D=\frac{\sin^{-1}\sqrt{2r-r^2}}{\sqrt{2r-r^2}}L=KL$$

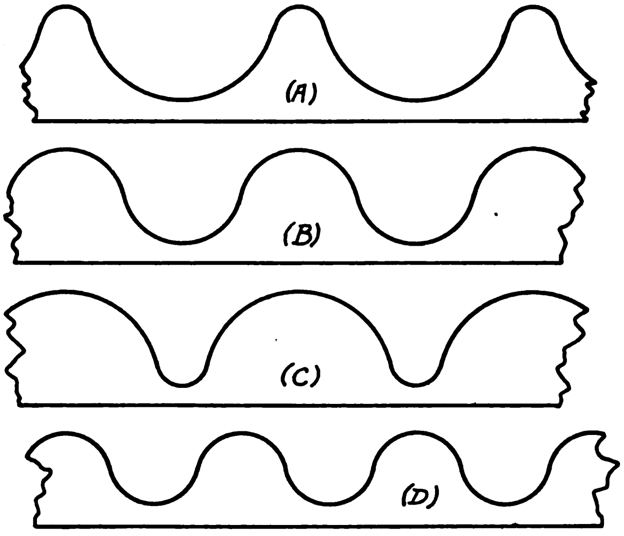

Fig. 5

Remarks

In Example 1 it was anticipated that there exists an infinite number of correlated values for h, R_1, and R_2, assuming r constant. In the foregoing treatment, K was seen to depend on r only, and, consequently D depends entirely on r and L. This fact is illustrated in Fig. 5. Here the four types of corrugations shown are drawn to the same scale and same profile index. All four will give the same developed length over an equal length L. The first three types have the same depth h and pitch P, but (A) and (C) have the values for R_1 and R_2 interchanged, while (B) has the same radius for "crest" and "trough" (*i.e.*, $R_1=R_2$). In all three the sum R_1+R_2 has the same value. The corrugation of (D) is finer than the preceding three, but, as said before, it will produce the same developed length as the other corrugations. In conclusion, the theorem is stated, *viz.*, that:

Circular corrugations having the same profile index will produce the same developed length over the same length L, no matter what their absolute value of pitch, depth, and "crest" and "trough" radii may be, provided there is a whole number of semi-cycles within the interval L.

Power Calculations for Elevators by the Method of Probabilities

PART II

STANDARDIZATION OF METHOD FOR SELECTION OF FEEDERS

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IT is now worth while to apply the method described in the previous section of this article to various groups of elevators and so establish tabulated data from which the feeder sizes to any such group can be picked without going through the detail calculations that have been outlined. We shall first consider the single elevator, then the group.

In Table V are given the results of a series of calculations for an elevator rated at 2500 lb. contract load and 600 f.p.m. contract speed, acceleration time 5.0 sec., resistance control. With full-load up motion, this elevator will just reach its contract velocity and come to rest in 6.8 sec. and travel 46.5 ft., which will be called its D_m value. It is assumed that the standing time at the landing is 7.0 sec. The accelerating current is taken at 210 amp.; the running current at 140 amp. In each case, the duty-cycle factor is determined as in Equation (6). The duty-cycle period is the time the car is in motion while the distance traveled is covered, plus the 7 sec. standing time. The distance traveled is assumed to be the average distance between stops, as treated in Part I of this article.

TABLE V

Distance Traveled in Feet	Duty-cycle Period in Sec.	Duty-cycle Factor	R.M.S. Amps.
10	9.9	0.554	78
20	11.25	0.650	91
30	12.3	0.693	97
40	13.25	0.722	101
46.5 (D_m)	13.8	0.800	112
50	14.2	0.908	127
57.5	14.9	1.000	140
60	15.15	1.021	143
70	16.15	1.072	150
80	17.15	1.085	152
90	18.15	1.078	151
100	19.15	1.050	147

The results are plotted in Fig. 13. The shape of the resulting curve is explained by the fact that up to 46.5 ft.—the D_m distance traveled when the car just reaches its contract speed (600 f.p.m.) and at once retards to stop—the accelerating input r.m.s. current over the duty-cycle period is but a comparatively small part of the maximum starting current reached. The accelerating r.m.s. value reaches a maximum when the car travels the distance 46.5 ft. and then decreases as the distance traveled increases; whereas the running current, being constant, has a high r.m.s. value. Therefore for any travel greater than 46.5 ft., the running current adds a considerable r.m.s. amount to the decreasing r.m.s. of the accelerating input. Eventually the accelerating r.m.s. value decreases to a point where the total r.m.s. current also begins to decrease, which point, in this case, occurs when the travel is 80 ft.

Of course if the standing time t_s were less than 7 sec., the r.m.s. accelerating input would reach higher values, but if the car stops at all to let passengers on or off and the operator opens and closes the car gate and landing door, the standing time allowed is little enough. Even if the standing time were zero and the car merely came to rest to start again, the r.m.s. accelerating duty-cycle period is 6.8 sec., the duty-cycle factor is 1.044 and the r.m.s. amperes are 146 *i.e.*, 4.2 per cent greater than the full-load up-running current of 140 amp. Such conditions are approached very infrequently in practice.

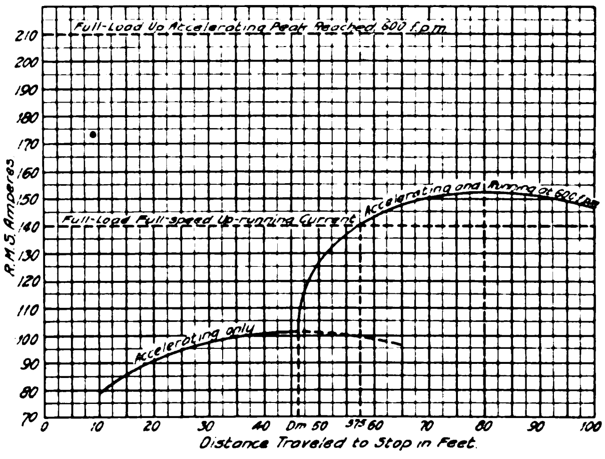

Fig. 13. A Typical R.M.S. Input-Distance Curve

For the duty cycle given in Table V and Fig. 13, the r.m.s. current reaches a maximum when the distance traveled is 80 ft. For this case $p_m^{\frac{1}{2}} = xp_a^{\frac{1}{2}}$ (see Equation 6), and *is the determining condition for maximum r.m.s.* value for any duty cycle. It can be easily shown that $(p_m^{\frac{1}{2}} + xp_a^{\frac{1}{2}})$ treated as a function of time has a maximum when $p_m^{\frac{1}{2}} = xp_a^{\frac{1}{2}}$. As the distance between stops increases beyond this point, the r.m.s. current decreases toward the full-load up-running current, which it would eventually reach on very long duty-cycle periods. At 200-ft. run, the duty-cycle factor is 1.019, and the r.m.s. amperes are 143; or less than when the distance traveled is 80 ft.

It has been shown by test that *the maximum duty cycle occurs when the stops are infrequent*, and that, with the usual equipment, where the total hoist is in the neighborhood of 100 ft., the measured maximum duty cycle occurs when the car makes a full run without stops.

But, the distance of 80 ft. is considerably greater than the average start-to-stop distance during arrival traffic, even including express runs. In view of this fact, and also in view of the other allowances for safety made previously, *it will be amply safe if the conductors to a single unit or elevator be selected on the basis of the full-load up-running current* for which the distance traveled is 57.5 ft. (Fig. 13). This makes the task of determining the proper size of conductor an easy matter, by merely reading the full-load up-running current. This conclusion has been amply checked by test. As a matter of fact no case has been found in which the r.m.s. exceeded 85 per cent of the full-load up-running current. It is not necessary to give the results for other ratings or for other values of t_s, for the same rule as to maximum r.m.s. value holds true, except that for generator-voltage type control the maximum r.m.s. value is a slightly greater fraction of the full-load up-running current than for resistance control with the same values of t and t_s. This is because with voltage control the car and load reaches maximum velocity in less time than with rheostatic control.

Feeders to Groups of Elevators

When the input to a group of motors is to be determined, then, as has been shown, the inputs to the individual motors combine in such ways that the resultant is more nearly an average than a sum. If the number of motors is large, or rather if they stop and start with reasonable and ordinary frequency, the average input and its r.m.s. may be determined by Equation (3). Thus,

$$I_A = pNI$$

and its r.m.s. value may be taken from Fig. 8 which gives the relation between average and r.m.s. currents for various values of p.

The input to each machine is divided into two parts, *viz.*, the accelerating input and the running input for each of which the above formula must be applied.

A very liberal overall operating factor T_r/T_t, during the arrival peak, which as has been pointed out is the maximum condition, is 0.5. As has been shown, the r.m.s. input to each unit is a maximum when $p_m^{\frac{1}{2}} = xp_a^{\frac{1}{2}}$, from which, $p_m/p_a = x^2$. Now, $p = 0.5$. Also $p_a + p_m = p = 0.50$. Therefore $\dfrac{p_m}{0.5 - p_m} = x^2$.

For resistance control, full load, and up motion, $x = I_a/I_m = 1.50$ (see Table I). So $x^2 = 2.25$. It follows that $p_m = 0.34$ and $p_a = 0.50 - 0.34 = 0.16$. For other possible duty cycles with $t_s = 7.0$ sec., the r.m.s. input will be less than for this cycle.

Then, for accelerating input, using Equation (3)

$$I_{Aa} = 0.16\,NI_a$$

and

$$I_{AM} = 0.34\,NI_M.$$

For 600-f.p.m. 2500-lb. resistance-control elevators on up motion with full load in the car, $I_a = 210$, $I_m = 140$ (see Table I). Therefore, by using Equation (3) with these values substituted when $p_a = 0.16$ and $p_m = 0.34$, the data for Table VI are computed.

The data given in Table VI are for full-load up motion. But, as a matter of fact, during arrival traffic the passengers leave the cars at the stops so that the car usually arrives at the top floor with few if any passengers and with light load. The average load during the up travel is likely to be balanced load. Furthermore, if no passengers left the car before it reached the top landing, it would make no stops and the r.m.s. input would approach the full-load running current on up motion, which is less than the r.m.s. values when stops are made. See Table V for long runs. Therefore, if the r.m.s. values in Table VI are used in determining the input for full-load up motion, they are safe even under worst conditions.

TABLE VI

Number in Group (N)	Ave. Accel. Input (I_{Aa})	R.M.S. Accel. (I_{Ra})	Ave. Run. Input (I_{AM})	R.M.S. Run. (I_{RM})	Total R.M.S. Input (I_{RT})
6	201.6	282.2	285.6	331.3	613.5
8	268.8	369.4	380.8	430.1	799.5
10	336.0	413.3	476.0	518.8	932.1
12	403.2	483.8	571.2	616.9	1100.7
14	470.4	550.4	666.4	713.0	1263.4
16	537.6	618.2	761.6	807.3	1425.5
18	604.8	683.4	856.8	903.9	1587.3
20	672.0	752.6	952.8	1000.4	1753.0

But during arrival traffic the cars run down practically empty and make few if any stops. It is therefore necessary to determine the r.m.s. values for this condition. The mean of the r.m.s. input for up-motion full load and for down-motion light load (150 lb.) will be the overall r.m.s. value for arrival traffic, which, as has been pointed out, is the worst condition.

For this case the overall value of p is less than for up motion when the cars are making stops. It may be taken safely at 0.30. Then, as before, using the data of Table I for 150 lb. down motion, $x = 205/85 = 2.40$, or $x^2 = 5.76 = p_m/p_a$. But $p_m + p_a = p = 0.30$, whence $p_a = 0.0444$, and $p_m = 0.2556$. Therefore $p_a^{\frac{1}{2}} = 0.22$ and $p_m^{\frac{1}{2}} = 0.51$.

The maximum duty-cycle factor for this case is $0.51 + 0.22x = 1.04$ in terms of the running current for down motion 150-lb. load.

The r.m.s. input is $1.04 \times 85 = 91$ amp.

For groups of elevators operating under these conditions, use $p_a = 0.04$, and $p_m = 0.26$. The results are given in Table VII. The formulas are, from Equation (3), $I_{Aa} \times 0.04 = 205 \times N$, and $I_{Am} = 0.26 \times 85 \times N$.

The mean of the total r.m.s. current (I_{RT}) for Tables VI and VII is given to the nearest integral number in Table VIII.

The numbers in the column headed "Mean R.M.S. Value" give the proper continuous-current carrying capacity of the feeders to the several groups at 240 to 250 volts, not considering the matter of voltage drop. The decimals in the column headed "R.M.S. Value in terms of NI_M" shows what relation the r.m.s. input to the group has to the number of elevators (N) times the full-load up-running current per elevator (I_M).

TABLE VII

Number in Group (N)	Ave. Accel. Input (I_{Aa})	R.M.S. Accel. (I_{Ra})	Ave. Run. Input (I_{AM})	R.M.S. Run. (I_{RM})	Total R.M.S. Input (I_{RT})
6	49.2	111.0	132.6	162.0	273.0
8	65.3	140.0	176.7	205.0	345.0
10	82.0	164.0	221.0	245.0	409.0
12	97.5	190.0	265.0	292.0	482.0
14	115.0	217.0	308.5	336.0	553.0
16	131.5	243.0	353.5	372.0	615.0
18	147.6	270.0	398.0	430.0	700.0
20	164.0	298.0	442.0	473.0	771.0

This table begins with $N = 6$. For values of N less than 6, it is not wise to use such averages as are entirely safe at $N = 6$. Therefore, while such extreme variations are rare, it is preferable that when N is less than 6 the conductors be selected for the full-load up-running current times the number of elevators when this is less than 443. It will be as given in Table IX.

TABLE VIII

Number in Group	Mean R.M.S. Value	R.M.S. Value in Terms of NI_M
6	443	0.53
8	572	0.51
10	671	0.48
12	792	0.47
14	908	0.46
16	1020	0.455
18	1144	0.452
20	1262	0.45

When the same method is applied to elevators, rated at 600 f.p.m., 2500 lb., generator-voltage type of control, on up-motion with full load in the car, $I_a = 250$ and $I_m = 140$ (see Table I). While the accelerating input is somewhat higher than with rheostatically controlled cars rated at 600 f.p.m. for the same load, the accelerating time is less, and the net result is that the total r.m.s. input into similar groups is but slightly greater than for the 2500-lb. 600-f.p.m. equipment with resistance control. Thus, consider an elevator rated at 2500 lb., 600 f.p.m., generator-voltage type control, reaching full contract speed up motion with full load in $t_a = 3.0$ sec. from standstill. For this equipment, $D_m = 36.9$ ft. in 5.25 sec. The characteristic duty cycle is shown in Fig. 5.

For this case, from Table I, $x = 250/140 = 1.8$. Assume as before, $t_s = 7.0$ sec. Then for the maximum duty cycle up motion, with $p = 0.5$, $p_m + p_a = 0.5$ and $p_m/p_a = x^2 = 3.24$; whence, $p_a = 0.1179$, $p_a^{\frac{1}{2}} = 0.34$, $xp_a^{\frac{1}{2}} = 0.612$, and $p_m = 0.3820$, or $p_m^{\frac{1}{2}} = 0.612$. Therefore the maximum duty-cycle factor for this case is 1.224, and the r.m.s. amp., $1.224 \times 140 = 170.8$.

On down motion with 150 lb. in the car, and $p = 0.30$, $x = 205/90 = 2.25$ (see Table I), $x^2 = 5.06$. Then $p_a = 0.06$, $p_m = 0.24$, and $xp_a^{\frac{1}{2}} = 0.55 = p_m^{\frac{1}{2}}$. The r.m.s. value $= 1.1 \times 90 = 99.0$.

For a group of 10 such elevators, the up full-load accelerating r.m.s. value $= 10 \times 0.1179 \times 250 \times 1.35 = 400$; the up full-load running r.m.s. $= 10 \times 0.382 \times 140 \times 1.07 = 572$, and the total up-motion r.m.s. $= 972$.

TABLE IX

Number in Group	Conductor Rating in Amp.
1	140
2	280
3	420
4	443
5	443

On down-motion 150-lb. load, the accelerating r.m.s. is $10 \times 0.06 \times 203 \times 1.66 = 202$, and the running r.m.s. is $10 \times 0.24 \times 90 \times 1.15 = 249$. The total r.m.s. is 451.

The mean r.m.s. value for up-motion full load and down-motion 150-lb. load is 711, which is to be compared with 671 in Table VIII. The 2500-lb. 600-f.p.m. voltage control equipment has an r.m.s. value six per cent higher than the r.m.s. of the 2500-lb., 600-f.p.m. rheostatic equipment.

In order to avoid complication of data, Tables VIII and IX should be used for all the following ratings: contract speeds of 500 f.p.m., and 600 f.p.m., for 2000 lb. and 2500 lb., and for both resistance control and generator-voltage type of control. For loads above 2500 lb. at the same contract speeds and methods of control, the r.m.s. values in Tables VIII and IX should be multiplied by factors proportional to the change in load. This would be necessary for the reason that while the accelerating input varies as the square of the total mass moved, including car, counterweight, sheaves, armature, ropes, and load, of which the load constitutes about one quarter, all the masses vary approximately in proportion to the load. Furthermore, while the full-speed running input varies directly as the unbalanced mass moved, in the duty cycle which has been chosen as representing the maximum r.m.s. input for full-load up motion, the effect of a change in load is proportionally the same for the r.m.s. accelerating input and the r.m.s. running input. Therefore the multiplying factors are as given in Table X.

If in addition the speeds change, while the average rate of acceleration remains constant, as is practically the case for any given method of control, the r.m.s. input again varies directly with the speed.

Since resistance control is never used with speeds exceeding 600 f.p.m., the increased speed will occur only with generator-voltage type of control above 600 f.p.m. The multiplying factors are given in Table XI.

Thus, if the duty of 10 elevators be changed from 2500 lb. at 600 f.p.m. to 3000 lb. at 800 f.p.m., the multiplying factor for load is 1.2, and for speed is 1.33. The total factor is 1.2×1.33 = 1.6. The total r.m.s. input at 600 f.p.m. (Table VIII) is 671 amp. The required r.m.s. input is 671.0×1.6 = 1075 amp.

TABLE X

Load, Lb.	Multiplying Factor
3000	1.2
4000	1.6
5000	2.0

In the text under the heading "Example" in the previous installment of this article, a bank of 8 elevators rated at 2500 lb. 800 f.p.m., we found an r.m.s. value of 542 amp., while for a different load (3000 lb.) and duty cycle under the second example we found an r.m.s. value of 689 amp. For 8 elevators, Table VIII corrected by Table XI for speed of 800 f.p.m., at 2500 lb., gives an r.m.s. current of 760 amp. If the load also be changed to 3000 lb., as in the second example, then, from Table VIII and Tables X and XI, we find an r.m.s. value of 910 amp. But for the conditions given under the examples, 542 r.m.s. amp. in one case and 689 amp. in the other are correct. Table VIII was devised to establish an easy and direct means of selecting feeders that would safely meet the worst conditions likely to occur. At that, the values given in Table VIII are materially lower than those assumed in selecting feeders by the N.E.C. Rules.

TABLE XI

Speed F.P.M.	Multiplying Factor
700	1.17
800	1.33
900	1.5

Using Tables VIII and IX and the factors given in Tables X and XI, it is possible to select the feeder capacity for any usual group of elevators of any usual rated load and contract speed.

Numerous tests of different groups of elevators of different duties have failed to show a single case where the values thus obtained are not conservative. It is well to repeat here that, in all of the foregoing consideration, voltage drop has not been considered.

The method of determining the probable peaks and their frequency for use in selecting overload protection has also been considered at length.

Summary

It has been shown and checked by tests that the conductors to individual elevator hoisting engines can be safely selected for the full-load up-running current.

It has been shown and checked by test that the feeder conductors to groups of elevators can be safely selected on the basis of the r.m.s. current values given in Tables VIII and IX and the tables of multiplying factors, Tables X and XI.

(Concluded)

The Effect of Temperature on Materials Required in Turbine Design

Mechanical Problems—Metallurgical Questions—Review of Flow Data

By S. H. WEAVER
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Steam turbine development during the past few years has proceeded along the lines of more efficient steam cycles. With all other possibilities already put to use, the present trend is toward higher temperatures. The flow of metals when under stress and at temperatures within the range of 700 to 1000 deg. F. introduces special problems in mechanical design. This article reviews present knowledge and points out the requirements of the immediate future.—EDITOR

THE constant endeavor to increase the thermal efficiency of the steam turbine has resulted, since the beginning of the commercial turbine about 25 years ago, in a continual increase in the temperature and pressure of the steam used. Both steam temperature and pressure increased together until about five years ago when the temperature increase halted at the maximum of 750 deg. F. This limit in temperature was set by the materials used in turbine construction because all of the commercial steels exhibited a very rapid change in physical properties at temperatures immediately above 750 deg. F. (400 deg. C.).

With the halt in the temperature increase, turbine development for higher efficiencies then proceeded along several distinct lines, in all cases with a view to improvement in the heat cycles employed. One was the improvement exemplified by the use of mercury in the boiler and turbine. Other developments included the use of regenerative processes and the resuperheating of the steam at an intermediate pressure to the initial temperature. Especially important was the rapid increase in the steam pressure which resulted in a sudden jump from 600 to 1000, 1200, then 1400 lb. per sq. in. steam pressure. All methods were successful in obtaining better economy in turbine operation, but a further improvement in efficiency can be made by increasing the initial temperature of the steam. It is estimated that turbine heat consumption will decrease about four per cent for each 100 deg. F. above the 750 deg. F. initial steam temperature. Such an increase will justify a thorough study of the high-temperature properties of materials that enter into steam-turbine construction.

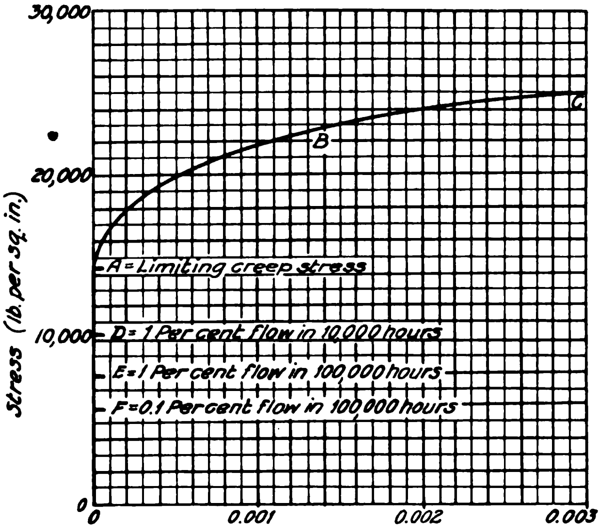

Fig. 1. Flow of 0.23 Carbon Steel Under Stress and at 900 Deg. F.

Mechanical Problems

Steels flow or elongate continuously in the direction of the strain when the metal is subjected to both high temperature and stress. The rate of metal flow is measured in years of time. This property of the materials introduces new problems in the design of moving machinery which must operate under high-temperature conditions.

In a high-temperature steam turbine, consideration must be given to the change in axial clearance between diaphragm and wheel where the clearance at the hub and at the rim of the wheel should not be permitted to vary much by reason of a gradual increase in diaphragm deflection, or dishing, over a long period of time.

The alignment of the stationary nozzles and rotating buckets with respect to the steam flow would be changed by the radial flow of the metal in the disk. Such a long-time movement would eventually affect the efficiency of operation and thereby limit the design especially for short buckets on the larger diameter wheels.

With a separate turbine unit for the high-pressure steam, rotating at 3600 r.p.m., the small specific volume of the steam and short length of buckets permit a rotor with the wheels made an integral part of the shaft.

For better efficiency, the steam after passing from the high-pressure turbine should be resuperheated to a high temperature before entering the low-pressure turbine unit. In the low-pressure turbine rotor, particularly for the larger rated outputs, the disk wheels are made separately and assembled on the shaft by some form of shrink fit. If the higher temperatures of a resuperheated-steam turbine were permitted to reach the fit between the wheel and shaft, the flow of metal at a definite rate when under the temperature and shrinkage stress would tend to gradually relieve the effective shrink fit allowances.

The massive bolts which clamp the upper and lower stationary shells must have a definite initial strain to prevent steam leakage through the shell joints. The flow of metal in the bolts by reason of the high initial stress and temperature would necessitate a periodic tightening of the bolts.

The mechanical fastening of the buckets to the disk wheel is influenced by any slow flow in the metal and must be studied for permanence of tightness of fastening and for changes in resonant vibration periods.

The foregoing consideration indicates some of the new problems in the mechanical design of a high-temperature steam turbine that are introduced by the property of the material to slowly flow in the direction of the strain. The nature of these problems must be definitely understood in order that turbines manufactured on a commercial basis may be designed with a view to satisfactory operation and with provision for all possible contingencies.

Metallurgical Questions

Not all of the high-temperature characteristics of the different steels are known. The steels that have been studied by the various investigators were usually at the very high temperatures and high rates of flow used in stationary apparatus, such as boilers, furnaces, and oil-cracking drums. Very little work has been done in the transition range from 700 to 1000 deg. F. where the rapid changes from high to low strength values occur. This is the temperature range in which the turbine designer is particularly interested.

This range from 700 to 1000 deg. F. lies near the beginning of recrystallization in some of the cold-worked steels, which is about 975 deg. F. for carbon steel. The presence of the lowest recrystallization temperatures in and above the transition range gives rise to many questions such as the permanence of heat treatment of the metal when the turbine is operating at say 700 to 900 deg. F. Long-time flow tests have usually been made on steels in the annealed or softest condition, on the supposition that heat-treated steels subjected to high temperature would eventually reach the annealed condition. However, that change may require a very appreciable time, especially with relation to a machine like the steam turbine. On that account it is desirable to know what would be the behavior of a heat-treated steel when tested below the recrystallization temperature, not only with reference to its first distortion but also with reference to its long-time changes and the values after a period of years.

Microscope studies of the structure of various steels have been made by several investigators on specimens subjected to temperature for six months to a number of years and these showed that below 1000 deg. F. all steels tested had stability of grain structure and of chemical combination in the crystals. If the steel is subjected to both strain and temperature it is possible that any deterioration of structure would be assisted

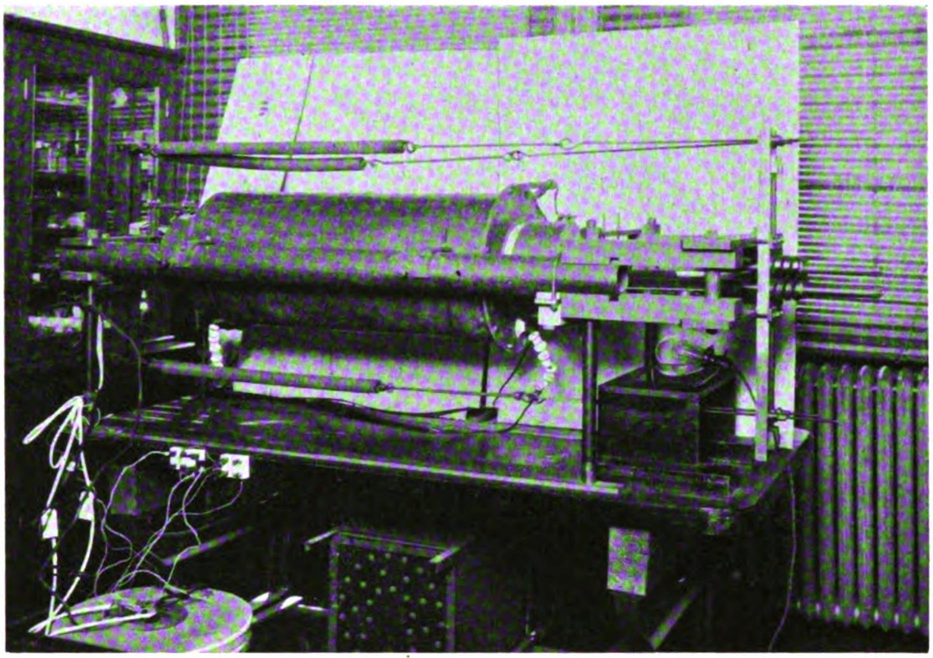

Fig. 2. Electrically-heated Furnace Designed to Measure the Flow in Metals When Under Stress at Elevated Temperatures. This furnace has been in service for several years but has been remodeled since this photograph was taken

by the strain and occur at a lower temperature. On the other hand it is possible that merely the rate of structural change would be increased.

There is also the question of the effect of various alloys and of the combination of alloys in the steel. Alloy steels have been studied extensively for use at the higher temperatures, but not so thoroughly in the range of interest to the turbine designer. In that temperature range, which covers the rapid changes in physical properties, some of the lower percentage of alloys in the steel may have an additional importance.

There are, in addition, many other important questions such as the oxidation, corrosion resistance, machinability, fatigue properties, and short-time tests, all of which must be considered before a steel can be finally selected for some special part in a high-temperature steam turbine.

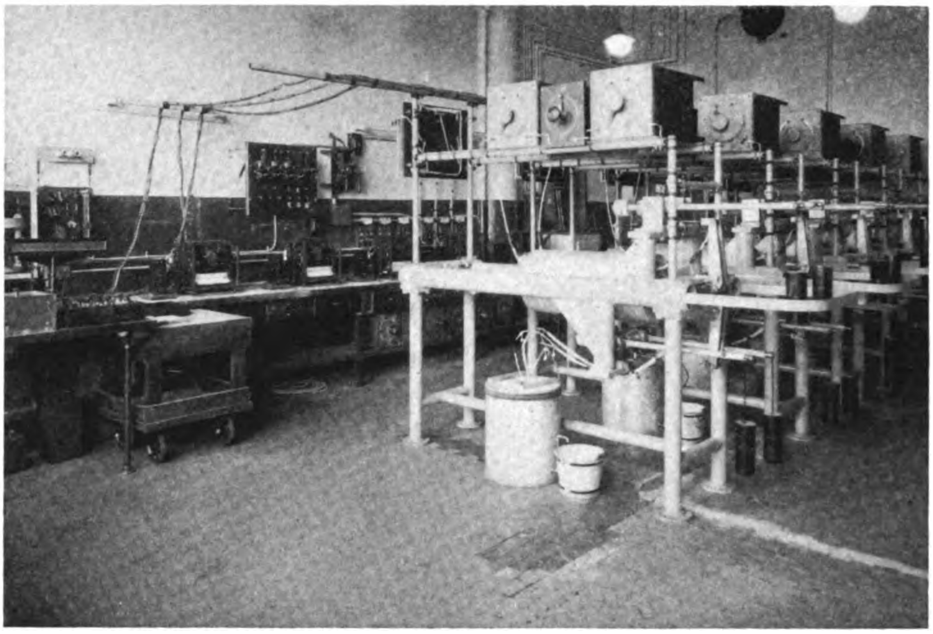

Fig. 3. Battery of Five of Six New Flow-rate Furnaces with the Controlling, Recording, and Electrical Measuring Equipment at the Left

Review of Flow Data

Values of "limiting creep stress" for various temperatures and materials have been published from time to time. No positive relation has been established between the "creep limit" and the definite "flow rates" of the metals. The distinction between these terms can be shown by an example.

Ample information is available about steel containing 0.23 per cent of carbon. Fig. 1 is a curve of such results as might be expected on a typical sample of this steel when tested at 900 deg. F. The points on the curve represent tests on a series of specimens all from the same sample but each tested at a different stress. For example, one specimen of this steel is held at 900 deg. F. and with an applied constant stress of 25,000 lb. per sq. in. The continuously increasing elongation is noted and plotted over a long period of time until a constant or minimum rate of increase in the elongation is established. This constant or minimum finally attained is 0.003 in. per day (per inch gauge length) and this value is plotted as point *C* on the curve. The same test is made on other specimens from the same sample and at the same temperature but at other constant stress values. The corresponding rates of elongation as finally attained give the curve *A B C* for 900 deg. F. This curve represents high rates of elongation; the point *C* at 25,000 lb. per sq. in. would fail in about one month. For a negligible or zero rate of elongation the curve approaches the stress ordinate at the point *A* at 14,500 lb. per sq. in., which is called the "limiting creep stress."

But if elongation readings of greater precision are taken for stress loads less than the point *A*, it is found that a metal flow still exists but at a much reduced rate. At the point *D*, 10,500 lb. per sq. in., there is a flow of the metal in the direction of the tension at the rate of one per cent in 10,000 hr. (approximately 14 months). At the point *E*, 7800 lb. per sq. in., the flow rate is one per cent in 100,000 hr. (11.4 yr.). At the point *F*, 5800 lb. per sq. in., there is a probable flow rate of 0.1 per cent in 100,000 hr. The ultimate strength at 900 deg. F. for a short-time test is about 42,000 lb. per sq. in.

Prof. F. H. Norton(1) has demonstrated that the curve in Fig. 1 between the point *A* and the origin can be represented by an exponential function of the form:

$$y = mx^n$$

where y is the tension stress and x the corresponding rate of metal flow. His tests covered the temperature range of 900 to 1500 deg. F., the rates of flow from 1 to 100 per cent in 100,000 hr. and nineteen steels, including low carbon, low alloys, stainless, and a few austenitic steels. The exponent n clustered about the average of one-fifth but ranged from one-third to one-seventeenth. The experimental proof was from A to E in Fig. 1 and the curve must pass to the zero value at the origin.

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(1) F. H. Norton: *The Creep of Steel at High Temperatures*, McGraw-Hill Book Co., Inc., New York, 1929.

For a constant temperature by plotting the logarithm of the stress and the logarithm of the rate of flow, the result is a straight line. This is important to the experimenter with respect to the accuracy and number of points to test; and to the mechanical designer who can project the straight line and estimate the minute flows that affect the construction by changes in the fit and strain allowances.

The first time a steel is stressed at a given temperature, the elongation starts with a very high but decreasing rate of flow. The action of the elongation is to "work harden" the steel and thus increase its resistance to flow. This "initial flow" may extend over a period from several days to weeks before the rate of flow becomes constant. Upon a second heating to the same temperature the initial flow does not again occur; but if an increased temperature is applied more work hardening and an additional flow is found.

The investigators do not always include the initial flow in their published data. It is of particular importance to the mechanical designer who must know and provide for the amount of relief in the initial fit or strain. For example, Kanter and Spring(2) give, for a 0.35 carbon steel held at 800 deg. F. and 10,000 lb. per sq. in. stress, a total elongation per inch of 0.00065 in. for the first 500-hr. test, for quenched and drawn and for normalized treatments; and 0.00034 in. for the steel when annealed. For the second 500-hr. period, each had the same increase of elongation, 0.00008 in. While these values are large, other types of steel can give negligible amounts of initial flow. These initial elongations are often of a magnitude which the mechanical designer must allow for in advance with a suitable recognition of the effect of such flow on stress distribution, shrink fits, and initial strain.

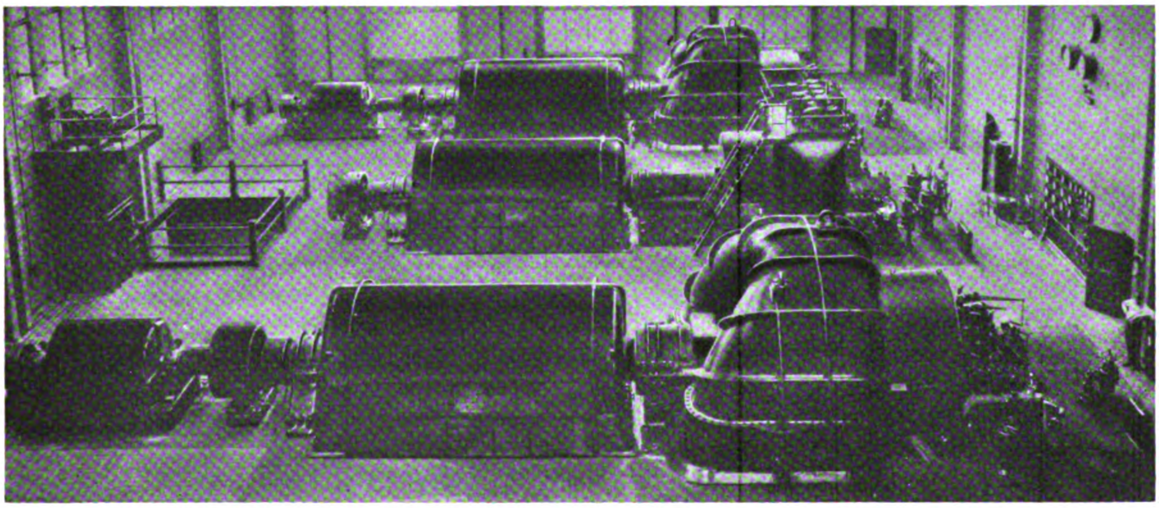
Several experimenters have shown that while the carbon content of the steel has a negligible influence at 1000 deg. F. and above, in the temperature range in which the steam turbine designer is interested the carbon percentage in the steel is a very important factor in the stress-flow rates.

During the past five years, the General Electric Company has operated several flow-rate furnaces in its Research Laboratory, Fig. 2. The capacity of the furnace illustrated is four test bars held at the same temperature but independently stressed.

Six additional furnaces have been constructed and recently placed in operation (Fig. 3). These also are of four test-bar capacity each.

Hundreds of long-time tests have been made at various flow rates and temperatures on many types of steel, including some of high alloy composition.

The total equipment is being used to accelerate the investigation of steels of various types as well as other high-temperature materials.



The 165,000-kw. 3-unit Cross-compound Turbine-generator Set in the Philo Station of the Ohio Power Company

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(2) J. J. Kanter and L. W. Spring: *Long Time or Flow Tests of Carbon Steels at Various Temperatures*, Am. Soc. Testing Materials, 1928.

Oil-immersed Current Transformers

By I. H. SCLATER
General Transformer Engineering Department, Pittsfield Works
General Electric Company

THE growth of systems with the concomitant possibility of concentrating large blocks of power has resulted in a demand for current transformers with great mechanical strength. It has resulted also in emergency conditions which often demand that short-time overloads be imposed on current transformers in order to give continuity of service. To meet these demands a new type of oil-immersed current transformers has been developed with distinctly superior mechanical strength and overload thermal characteristics.

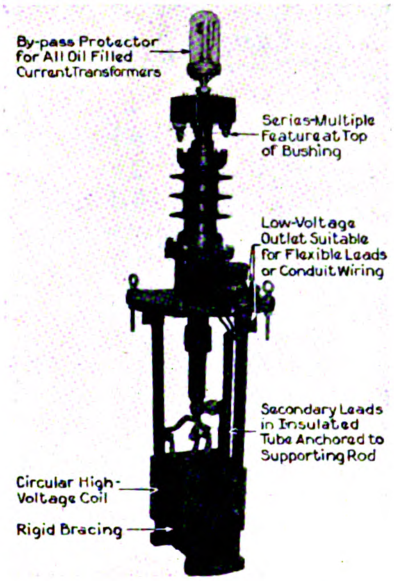
By-pass Protector for All Oil Filled Current Transformers
Series-Multiple Feature at Top of Bushing
Low-Voltage Outlet Suitable for Flexible Leads or Conduit Wiring
Secondary Leads in Insulated Tube Anchored to Supporting Rod
Circular High-Voltage Coil
Rigid Bracing

Fig. 1. General Construction of New Type Oil-immersed Current Transformers

These new current transformers are designed to successfully carry 125 per cent normal current continuously without exceeding 55 deg. C. rise. The thermal capacity is sixty times normal r.m.s. value based on an initial temperature of 105 deg. C. and a maximum temperature of 250 deg. C. The mechanical strength for a few cycles is approximately four or five times that determined by their thermal rating. Fig. 1 shows the general construction of the transformers. It is characteristic of the entire group.

Accuracy

The transformer characteristics are shown in Fig. 2. Individual transformers are not expected to deviate from this curve by more than plus or minus 0.5 per cent on ratio and plus or minus 15 minutes on phase angle. All transformers are suitable for 25 to 125-cycle operation with accuracies at 25 and 60 cycles as shown in Fig. 2.

Connections

Each transformer is provided with a series-multiple high-voltage winding. Changes from the series to the multiple connections are made at the top of the bushings (Figs. 1 and 3). For higher current ratings the links, etc., are protected from corrosion, as shown in Fig. 4.

Windings

Circular coils, affording maximum mechanical strength, are employed for all ratings. The core and coils are rigidly braced as shown in Fig. 5. The high-voltage coils are wound with paper-covered conductors and are liberally insulated between turns and layers.

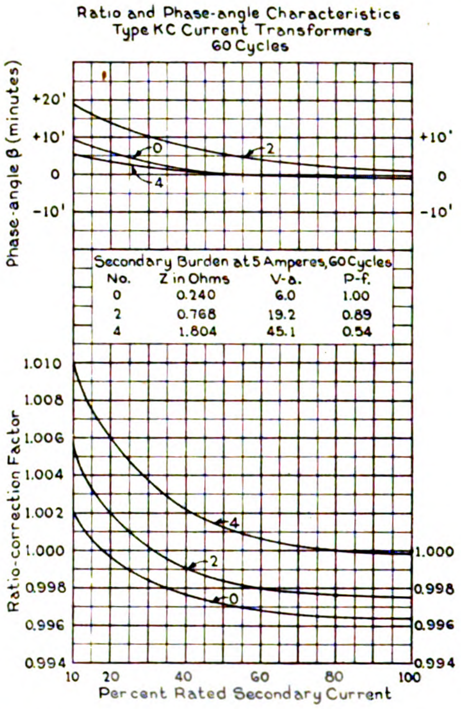

Fig. 2. Ratio and Phase-angle Characteristics for the New Current Transformers

Herkolite is used as the major insulation, *i.e.*, insulation between the high-voltage and the low-voltage windings. Herkolite cylinders are used on the lower-voltage transformers and the combination of Herkolite cylinders and flanged collars are used on high-voltage designs (Fig. 5).

The coils are first vacuum dried and varnish impregnated, to thoroughly impregnate turn and layer insulation. The complete transformer is then given vacuum oil impregnation to insure a thorough drying of all insulating materials.

Bushings

Oil-filled bushings are used on transformers for 50-kv. circuits and above.

Tanks

The all-welded steel tanks are made of special copper bearing steel and are thoroughly cleaned and painted with a special gray paint of high weathering qualities, giving greater resistance to corrosion. They are self-draining. Oil sampling valves or plugs are provided so that samples of oil may be drawn from the bottom of the tank.

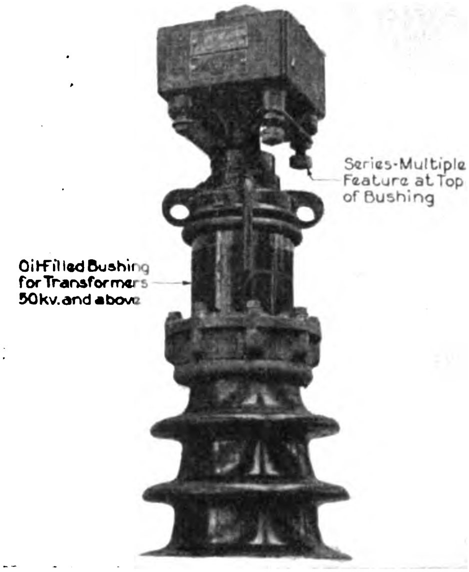
Series-Multiple Feature at Top of Bushing
Oil-Filled Bushing for Transformers 50kv. and above

Fig. 3. Top of Bushing, Showing Series-multiple Terminal Box for Current Transformers

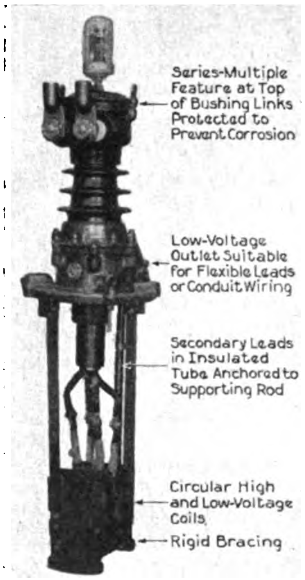
Series-Multiple Feature at Top of Bushing Links Protected to Prevent Corrosion
Low-Voltage Outlet Suitable for Flexible Leads or Conduit Wiring
Secondary Leads in Insulated Tube Anchored to Supporting Rod
Circular High and Low-Voltage Coils
Rigid Bracing

Fig. 4. Internal Construction and Details of High-voltage Bushing of Instrument Current Transformer Rated 25/125 Cycles, 400/800-80/160: 1 Ratio

By-pass Protectors

The reactance of the current transformers may act as a choke coil in case of high-frequency surges causing a building up of voltage. This may involve danger to the apparatus, particularly on large transformers with a heavy secondary burden. To eliminate this danger, by-pass protectors are employed with all oil-immersed current transformers. The by-pass protector consists of a resistance and vacuum gap shunted across the terminals of the current transformer. This protector allows the high-frequency surges to pass by the transformer without injury (see Fig. 1).

General

Transformers are shipped oil-filled, eliminating the necessity of their being dried out before installation. Cover-suspended construction is used, rendering the core and coils accessible for examination or repair.

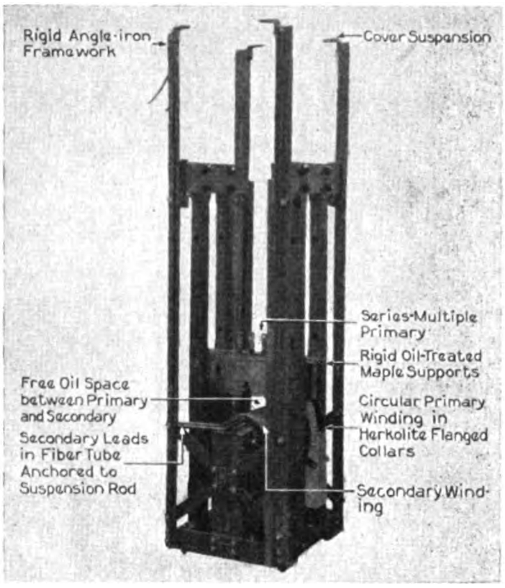
Rigid Angle-iron Framework
Cover Suspension
Series-Multiple Primary
Rigid Oil-Treated Maple Supports
Free Oil Space between Primary and Secondary
Circular Primary Winding in Herkolite Flanged Collars
Secondary Leads in Fiber Tube Anchored to Suspension Rod
Secondary Winding

Fig. 5. Details of Assembly of a 25/125-cycle 100/200-20/40: 1 Ratio Current Transformer for 115,000-volt Circuit

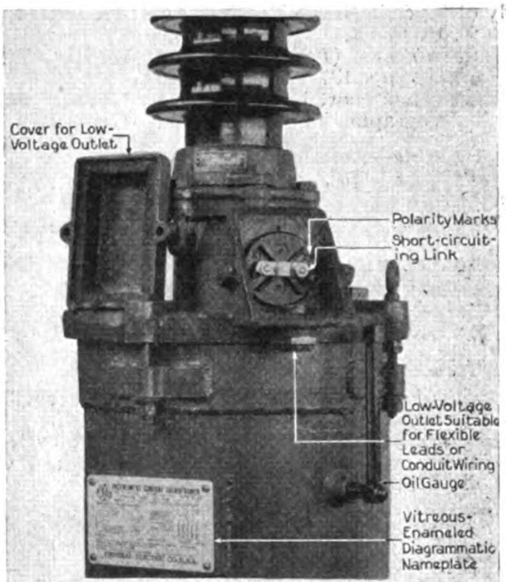
Cover for Low-Voltage Outlet
Polarity Marks
Short-circuiting Link
Low-Voltage Outlet Suitable for Flexible Leads or Conduit Wiring
Oil Gauge
Vitreous-Enameled Diagrammatic Nameplate

Fig. 6. External Details of a 25/125-cycle 5/10-1/2: 1 Ratio Outdoor Instrument Current Transformer for 37-kv. Circuit

Fixed secondary terminals are provided (Fig. 6), giving a construction which is suitable for flexible leads or conduit wiring.

Vitreous-enamel nameplates, mounted on the tank as shown in Fig. 6, provide the diagram of connections and polarity marks for the transformers.

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

Arc Welding

Arc Welding of Stainless and Corrosion Resistant Steels. R. D. Thomas.
Am. Weld. Soc. Jour., July, 1930; v. 9, pp. 90-98.

Condensers, Steam

Condensing Equipment.
N.E.L.A. Pub. No. 069, July, 1930; pp. 1-37.

Electric Control Systems

New Type of Remote Control. R. D. Bean.
Instruments, Aug., 1930; v. 3, pp. 535-537.
(On the use of Selsyn motors for such control.)

Supervisory Control of Unattended Substations. R. M. Harvey.
Elec. Engr. of Aust. & N. Z., July 15, 1930; v. 7, pp. 121-127.

Vacuum Tube in Stage and Mobile Illumination. H. A. Breeding.
Electronics, Aug., 1930; v. 1, pp. 237-239.
(The use of Thyratron tubes as control devices for lighting installations.)

Electric Heating

Experimenting With House Heating. J. C. Plankinton.
Elec. West, Aug. 1, 1930; v. 65, pp. 70-74.
(Results of tests on electric house-heating equipment in a home in Portland, Ore.)

Study of Electric House Heating. A. R. Stevenson, Jr. and F. H. Faust.
A.S.M.E. Trans. (*FSP*), May-Aug., 1930; v. 52, paper no. 20, pp. 137-142.
(Includes a short bibliography, p. 140, and numerous bibliographic footnotes.)

Electric Lighting—Aviation

Careful Planning Pays in Airport Lighting. F. S. Peterson.
Elec. Wld., Aug. 9, 1930; v. 96, pp. 259-260.
(Equipment and methods used at the Denver airport.)

Electric Power

Development of the Superpower System of the Chicago District. Wm. S. Monroe.
W. Soc. Engrs. Jour., Aug., 1930; v. 35, pp. 231-254.

Electric Transmission Lines—Descriptions

Transmission Over the Blue Ridge. O. W. Gatchell.
Elec. Wld., Aug. 2, 1930; v. 96, pp. 218-222.
(Illustrated description of a 110-kv., 60-cycle line of the Carolina Power & Lt. Co., between Canton, N. C., and Greenville, S. C.)

Faults, Electric

Kenetron Bridge Locates Power Cable Faults. F. H. Gooding.
Elec. Wld., July 26, 1930; v. 96, pp. 164-165.

Hydroelectric Development

Hydro Power Practise in Central Europe. A. V. Karpov.
A.I.E.E. Jour., Aug., 1930; v. 49, pp. 638-642.
(Abridgment.)

Insulating Oils

Acidity in Insulating Oils. G. L. Sumners.
Elec. Wld., Aug. 9, 1930; v. 96, pp. 261-263.

Design and Installation of Insulating Oil Piping for Electrical Substations. A. H. Beiler.
Heat. Piping & Air Cond., Aug., 1930; v. 2, pp. 676-682.
("The problem of oil handling in connection with electrical stations is a relatively new one, and there is almost no data available. The author presents essential information difficult to obtain from other sources.")

Insulation

Essential Factors in the Coördination of Line, Station and Apparatus Insulation. A. E. Silver and H. L. Melvin.
A.I.E.E. Jour., Aug., 1930; v. 49, pp. 684-688.
(Abridgment.)

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(Design of line insulation with special reference to lightning protection. Abridgment.)

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Instrument Repair and Standardization Laboratory. C. E. Fry.
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Lightning Protection for Industrial Substations. H. M. Towne.
Ind. Engng., Aug., 1930; v. 88, pp. 421-424.

Locomotives, Gas-Electric

Electric Transmission and Control of Power From Internal Combustion Engines for Transportation. S. T. Dodd.
A.I.E.E. Jour., Aug., 1930; v. 49, pp. 649-653.
(Abridgment.)

Oscillographs

New Portable Oscillograph. Claude M. Hathaway.
A.I.E.E. Jour., Aug., 1930; v. 49, pp. 646-649.

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Operating Facts from Mad River. John W. Mikels.
Power, July 15, 1930; v. 72, pp. 96-99.
("A two-year résumé of practical experience" at the Mad River plant of the Ohio Edison Co., Springfield, O.)

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High-Tension Line Protection by the Petersen Arc Suppressor.
Engr., Aug. 1, 1930; v. 150, pp. 126-128.

Protection of Alternating Current Generators.
Engr., Aug. 8, 1930; v. 150, pp. 138-139.
(Serial.)

Protection of Parallel Feeders and Interconnectors. W. Wilson.
Wld. Power, Aug., 1930; v. 14, pp. 109-115.

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A.I.E.E. Jour., Aug., 1930; v. 49, pp. 604-609.
(Annual report of an A.I.E.E. committee.)

Protective Devices for Electric Generators. W. Schäfer.
Engng. Prog., Aug., 1930; v. 11, pp. 211-215.

Radio Broadcasting

Long Distance Cable Circuit for Program Transmission. A. B. Clark and C. W. Green.
A.I.E.E. Jour., Aug., 1930; v. 49, pp. 642-646.
(Abridgment.)

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Proposed Standard Tests of Broadcast Radio Receivers.
Inst. Radio Engrs. Proc., Aug., 1930; v. 18, pp. 1282-1305.

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Reflection of Radio Waves From the Surface of the Earth. Lal C. Verman.
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Elec. Wld., Aug. 9, 1930; v. 96, pp. 270-271.
(Tabulated data comparing costs before and after electrification on several steam railroads. Excerpt from a World Power Conference paper by W. D. Bearce.)

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Modern Requirements for Protective Relays on Important System Interconnections. O. C. Traver and L. F. Kennedy.
A.I.E.E. Jour., Aug., 1930; v. 49, pp. 678-682.
(Abridgment.)

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Performance of Two Vessels With Electric Transmission Gear. W. J. Belsley.
Engr., Aug. 8, 1930; v. 150, pp. 154-156.
(Performance data for the turbine-electric "Viceroy of India" and the Diesel-electric "Brunswick." Abridged from a paper before the Inst. of Naval Architects.)

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Problem of the Mechanism of Spark Discharge. Leonard B. Loeb.
Franklin Inst. Jour., July, 1930; v. 210, pp. 15-30.

Steam Turbines

Application of Turbines to Power Generation. A. G. Christie
Power, Aug. 5, 1930; v. 72, pp. 208-211.
(Abstract of a paper presented at the World Power Conference.)

Use in Power Stations of Steam Turbines Having, With Their Auxiliaries, Large Overhead Capacities. Charles A. Parsons and Robert Dowson.
Wld. Power, Aug., 1930; v. 14, pp. 148-149, 151-154, 157.
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Transformers—Theory and Design

Effect of Transient Voltage on Power Transformer Design; The Behavior of Transformers With Neutral Isolated or Grounded Through an Impedance. K. K. Palueff.
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(Abridgment.)

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Advanced Mathematics for Students of Physics and Engineering. D. Humphrey. 312 pp., 1929, N. Y., Oxford Univ. Press. $4.25.

Airplane Welding. J. B. Johnson. 321 pp., 1929, Chgo.. Goodheart-Willcox Co., Inc. $3.50.

Applied Mechanics. Ed. 3. Alfred P. Poorman. 306 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $2.75.

Balancing of Oil Engines. W. K. Wilson. 279 pp., 1929, Phila., J. B. Lippincott Co. $10.00.

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Cost Finding for Engineers. Charles Reitell and Clarence Van Sickle. 518 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $5.00.

Die Casting Practice. Marc Stern. 270 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $2.50.

Diesel Engine Operation, Maintenance and Repair. Charles H. Bushnell. 285 pp., 1930, N.Y., John Wiley & Sons. $3.50.

Electric and Magnetic Circuits, Alternating Current and Direct Current. E. N. Pink. 124 pp., 1930, N. Y., Isaac Pitman & Sons. $1.00.
(A brief text in which "it is assumed that the student has some knowledge of electricity and magnetism." Forty-one pages are devoted to the properties and behavior of direct-current circuits, thirty-two to theories of magnetism and the magnetic circuit, and the remaining fifty-one to some of the properties of alternating-currents and their circuits. The treatment employed, both as to text-matter and theory, is elementary.)

Elektrothermie; Die Elektrische Erzeugung und Technische Verwendung Hoher Temperaturen. M. Pirani. (Editor.) 293 pp., 1930, Berlin, Julius Springer.
(This German book is not a complete or systematic treatise, but rather a series of contributions, by prominent German technicians, on electrical methods of producing high temperatures and on some of their industrial applications. These contributions are the outgrowth of a course of lectures delivered before the Extension Division of the Berlin "Technische Hochschule," and are edited by Prof. M. Pirani of that institution. A short introduction by the editor is followed by an extensive paper, contributed by R. Gross, dealing with the electric furnace and its current supply, particularly in connection with the electrical production of iron, steel and ferro-alloys. The melting of non-ferrous metals in the electric furnace is then discussed by M. Tama. This is followed by chapters on electrical methods of producing silicon carbide and similar products, and on the manufacture of graphite, calcium carbide and fused quartz. H. Pauling devotes a chapter to the electrical production of nitrogen from air, and M. Pirani follows with a discussion of the electric furnace in the research field. Prof. G. Keinath concludes the volume with a lengthy chapter on electric furnace measurements and measuring devices, including pyrometry.)

Elements of Steam and Gas Power Engineering. Ed. 3. Andrey A. Potter and James P. Calderwood. 367 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $2.75.

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(A central station engineer and manager in Vienna gives, in the first part of his little booklet, a discussion of the factors entering into central station power costs. This is followed by a presentation of the principles of electric rates and rate making. The concluding section deals with the effects of power factor on power costs and rate making.)

Grundlagen und Entwicklungen der Energiewirtschaft Österreichs. Oskar Vas (comp.) 189 pp., 1930, Vienna, Julius Springer. RM 20.00 (paper.)
(The post-war Austria, left with but little coal of value, has made great efforts in developing its water-power resources and in modernizing its electric-power industry generally. The results obtained are well depicted in this book. The volume is an official report of a committee of prominent engineers appointed as Austria's representatives at the recent World Power Conference in Berlin. The following topics are reviewed in the report: Austria's fuel and water-power resources, the electricity supply in Austria, the electrification of Austrian railroads, and the law and regulations of the Austrian electric utilities.)

Heat Power. Earle B. Norris and Eric Therkelsen. 376 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $3.50.

High Voltage Oil Circuit Breakers. Roy Wilkins and E. A. Crellin. 301 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $4.00.

Industrial Accounting for Executives. John R. Bangs, Jr. 449 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $5.00.

Introduction to the Study of Wave Mechanics. Louis de Broglie. 249 pp., 1930, N. Y., E. P. Dutton & Co., Inc. $4.25.
(This volume, which has been translated from the French by H. T. Flint, is written by the winner of the Nobel prize for physics in 1929. It contains "an authoritative and complete account of the new dynamical theory," and is "developed in a logical sequence from the ideas upon which it is based. The new principle of indeterminateness, together with recent experimental work on electronic diffraction, is amply discussed.")

Matter and Radiation; With Particular Reference to the Detection and Uses of the Infra-Red Rays. John Buckingham. 144 pp., 1930, N. Y., Oxford University Press. $3.00.

Materials of Engineering Construction. Francis W. Roys. 331 pp., 1930, N. Y., Ronald Press Co. $4.00.

Mechanical Engineers' Handbook. Ed. 3. Lionel S. Marks. 2264 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $7.00.

Modern Physics; a General Survey of Its Principles. Theodor Wulf. (Translated from the second German edition.) 469 pp., 1930, N. Y., E. P. Dutton & Co. $10.00.

Overhead Expense in Relation to Costs, Sales and Profits. A. Hamilton Church. 418 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $5.00.

Photocells and Their Application. V. K. Zworykin and E. D. Wilson. 209 pp., 1930, N. Y., John Wiley & Sons, Inc. $2.50.

(The scope of this little volume is very well expressed by the authors in their Preface, an extract from which reads as follows: "It is high time that the public in general should be introduced to the modern 'electric eye' and be taught its normal characteristics and its special idiosyncrasies. It has been the distinct aim of this book to do just that thing. The authors have attempted to assemble reliable information from the thousands of articles scattered throughout the world's literature, sift the significant from the inconsequential, and present the residue in the light of their own training and long experience with the subject. . . It is believed that in the chapters following the reader will find an understandable account—not too technical for the untrained man and not too shallow for the specialist—an accurate account of the origin and rise of the photocell, its behavior, and its functioning as a real entity of affairs. It is hoped that the general reader of this book will acquire not only a complete background of information in photoelectricity but also a practical knowledge of the art of making photocells and of using them in electrical circuits for picture transmission, television, sound projection, and for many industrial applications.")

Piping Handbook. J. H. Walker and others. 763 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $5.00.

Plant Location. W. Gerald Holmes. 275 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $3.00.

Practical Mechanics and Strength of Materials. Ed. 2. Charles W. Leigh and John F. Mangold. 420 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $2.75.

Principles of Iron Founding. Ed. 2. Richard Moldenke. 654 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $6.00.

Rechtsgrundlagen der Öffentlichen Elektrizitätswirtschaft in Deutschland. Ernst Henke, Hans Müller, and Fritz Rumpf. 237 pp., 1930, Berlin, Julius Springer. RM 14.50 (paper.)

(A short treatise on the legal aspects of the electric utility industry in Germany. It consists of three main parts, each written by one of the three authors, all of whom are attorneys for German public utility concerns. The first part presents a general review of the German conception of public utility regulation and control, the second part deals with the right-of-way of transmission lines, and the third outlines the laws and regulations of electric distribution. Numerous foot-note references enrich the text.)

Statistical Tables and Graphs. Bruce D. Mudgett. 194 pp., 1930, Bost., Houghton Mifflin Co. $1.75.

Street Lighting Practice. Ward Harrison, O. F. Haas, and Kirk M. Reid. 270 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $3.50.

("The subject matter here covered ranges from problems of a purely engineering character, such as the choice of equipment based on light distribution, the proper location of lighting units, series versus multiple circuits, the evaluation of glare, and installation and operating costs, to problems of contractural relations, of methods of financing, of maintenance provisions, and even of the history of street illumination. Much effort has been devoted to the selection and preparation of the charts, illustrations, and distribution curves, numbering more than two hundred in all, and particular care has been taken in every case to render them authoritative and complete." The above quotation from the Preface serves well to illustrate the scope of this new volume on street lighting. The work is one on practical street lighting equipment and methods rather than on any phase of illuminating engineering. However, there are several appendices which carry information sufficient for an elementary understanding of the technical points involved, such as definitions of terms, illumination measurements and calculations, street lighting principles, representative candlepower distribution curves, and the like.)

Strength of Materials. S. Timoskenko. 1930, N. Y., D. Van Nostrand Co., Inc.

Pt. I: Elementary Theory and Problems. 368 pp. $3.50.
Pt. II: Advanced Theory and Problems. 335 pp. $4.50.

(A two-volume work intended to cover rather completely the subject of strength calculations in engineering. In the author's words: "It is the aim of this book to present problems such that the student's attention will be focussed on the practical applications of the subject. If this is attained, and results, in some measure, in increased correlation between the studies of strength of materials and engineering design, an important forward step will have been made. The book is divided into two volumes. The first volume contains principally material which is usually covered in required courses of strength of materials in our engineering schools. The more advanced portions of the subject are of interest chiefly to graduate students and research engineers, and are incorporated in the second volume of the book. This contains also the new developments of practical importance in the field of strength of materials. In writing the first volume, attention was given to simplifying all derivations as much as possible so that a student with the usual preparations in mathematics will be able to read it without difficulty. The second volume is written principally for advanced students, research engineers, and designers. The writer has endeavored to prepare a book which contains the new developments that are of practical importance in the fields of strength of materials and theory of elasticity.")

Technique of Executive Control. Ed. 3. Erwin H. Schell. 171 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $2.00.

Television To-Day and To-Morrow. Sydney A. Moseley and H. J. Barton Chapple. 130 pp., 1930, N. Y., Isaac Pitman & Sons. $2.50.

("For the reader whose knowledge of the technical side of television is limited." Structural details of actual apparatus, as well as most of the photographic illustrations, pertain to equipment developed by John L. Baird, of England. Mr. Baird also contributes a "Foreword" to the volume. In addition to material on the Baird "Televisor," there is a chapter on the history of television, one on general details, one on synchronism, one on photo-electric cells and neon tubes, and one on television receivers. Such recent developments as television motion pictures with and without sound, "noctovision," "phonovision," color and stereoscopic television, etc., receive consideration. Numerous diagrams illustrating the principles involved, and photographs showing actual apparatus, help the reader to a better conception of television and its possibilities.)

Textbook of the Materials of Engineering. Ed. 4. Herbert F. Moore. 409 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $4.00.

Theory of the Potential. William D. MacMillan. 469 pp., 1930, N. Y., McGraw-Hill Book Co., Inc. $5.00.

Work Routing in Production, Including Scheduling and Dispatching. John Younger. 115 pp., 1930, N. Y., Ronald Press Co. $2.50.

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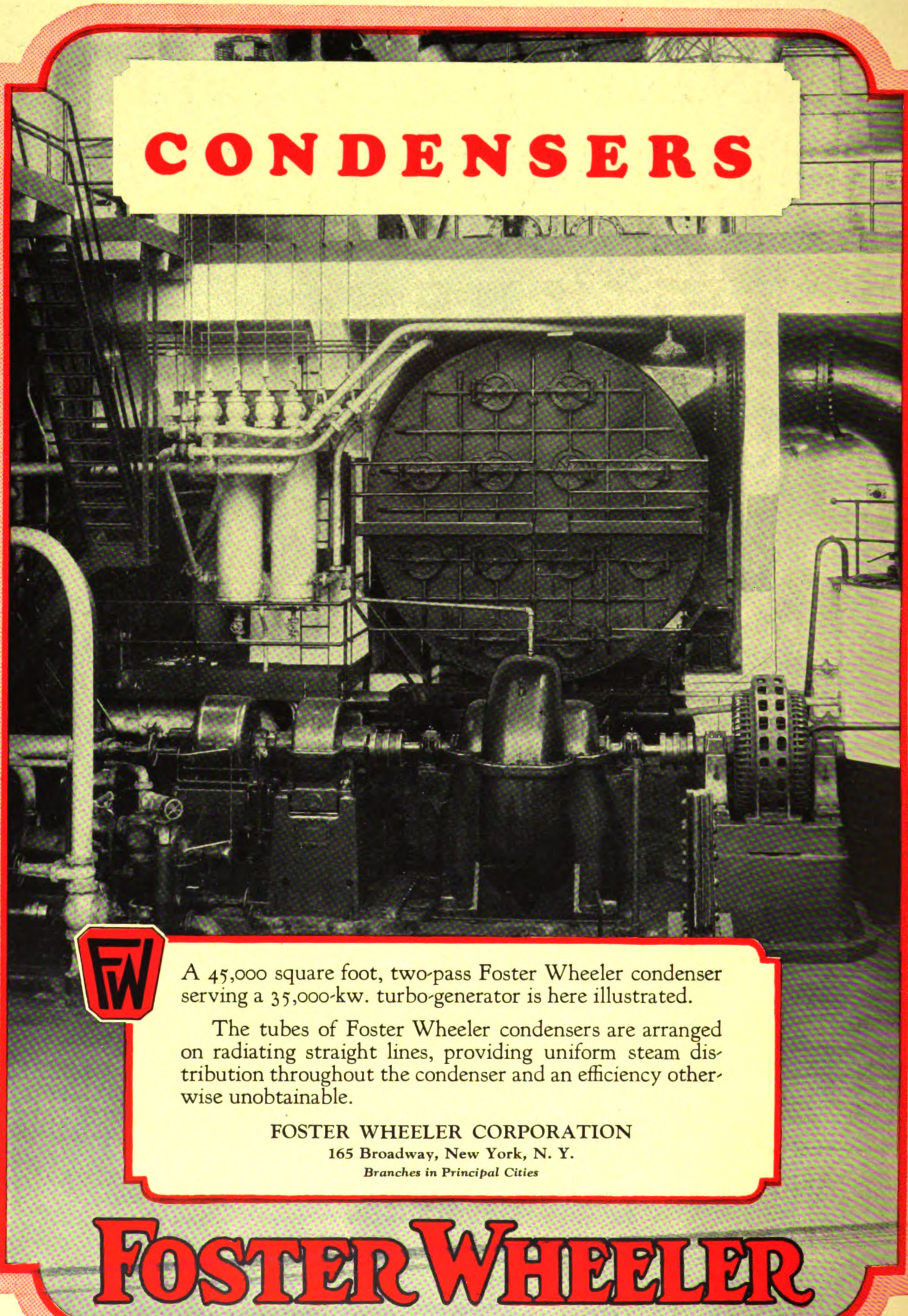
GENERAL ELECTRIC REVIEW

VOL. 33, NO. 12 DECEMBER, 1930

LIGHTING THE CENTERS OF TRADE

The world's largest building, the Merchandise Mart in Chicago, is floodlighted with some six hundred projectors, giving striking beauty to the structure and its reflection in the Chicago River. The general application of floodlighting is presented in detail on p. 690

In This Issue: *Power System Stability* *X-ray Apparatus* *System Power Flow*
Foundry Welding *Floodlighting* *Induction Motor Starting*
Cupola Blowing *Welded Building* *Selsyn Equipment* *Prof. Elihu Thomson*


CONDENSERS

A 45,000 square foot, two-pass Foster Wheeler condenser serving a 35,000-kw. turbo-generator is here illustrated.

The tubes of Foster Wheeler condensers are arranged on radiating straight lines, providing uniform steam distribution throughout the condenser and an efficiency otherwise unobtainable.

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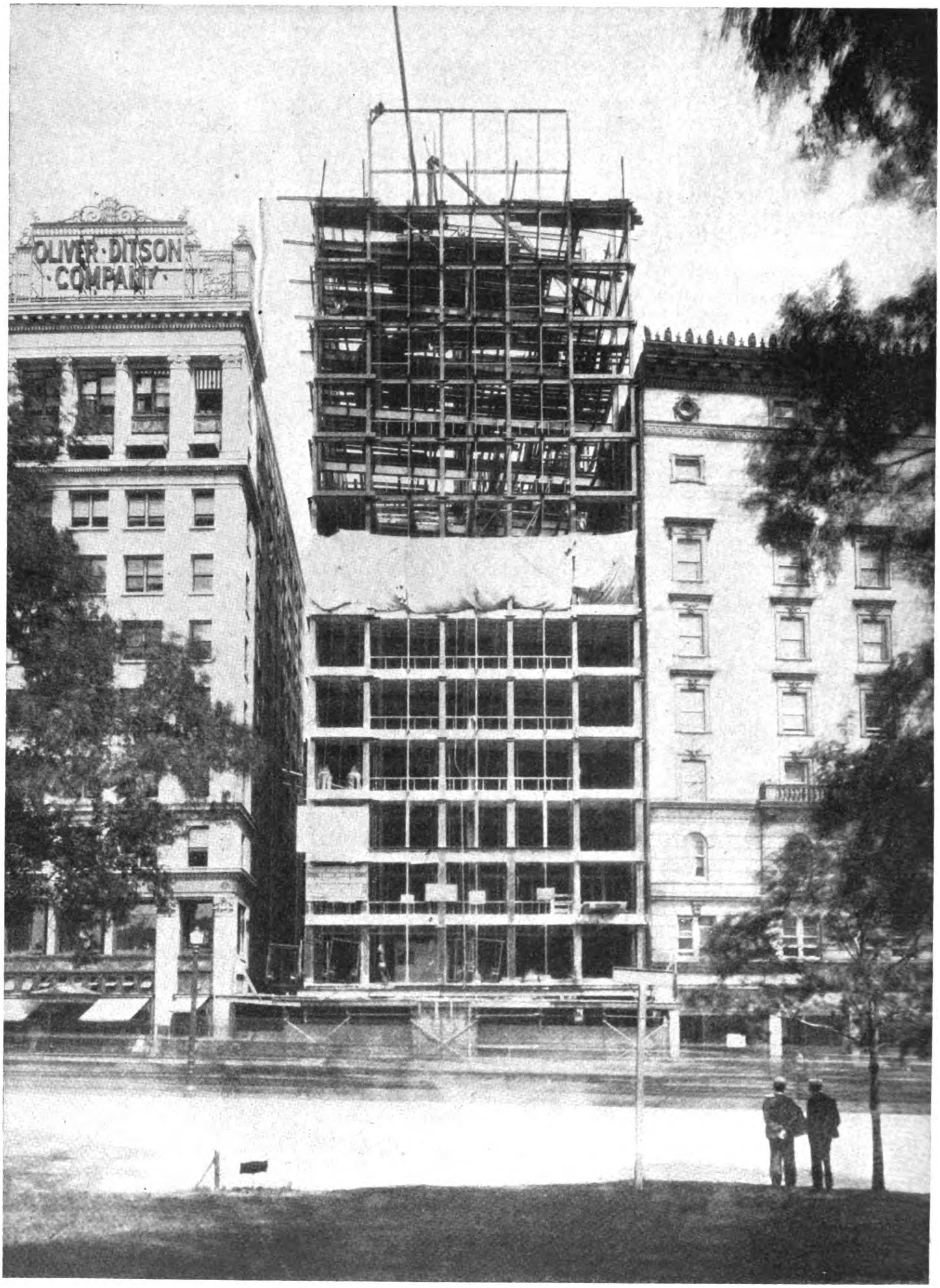
monthly by *INDUSTRIAL ARTS INDEX*, and weekly and annually by *ENGINEERING INDEX*: and abstracted monthly by *SCIENCE ABSTRACTS*



FOURTEEN STORIES OF FIELD-WELDED STEEL

The new Edison Illuminating Company Building, facing the famous old Common in the city of Boston (Mass.), provides a new chapter in the annals of structural welding. This building is described on p. 699

GENERAL ELECTRIC

REVIEW

Vol. 33 December, 1930 No. 12

SCIENTIFIC POLITICS

In an address delivered last summer, Mr. Owen D. Young, in touching on international affairs, made the significant statement that politics must follow economics, and that failures of statesmanship had sometimes resulted from the fallacious assumption that economics could be made to conform to political policy.

As this is being written, a political campaign is in full swing. Domestic politics, as well as international, should be based on economics, and in part on sociology. Now economics and sociology are, supposedly, sciences and their principles and applications should lend themselves to discussion in the scientific spirit, to dispassionate analysis and synthesis, with the sole object of reaching the truth. But instead, we find in this, as in all earlier campaigns, that political oratory often seems framed to appeal to emotion rather than to reason. We hear charges and countercharges that issues are deliberately befogged or evaded, that facts are distorted and prejudices stimulated.

To a visitor from Mars this might all seem very strange, but the history of science itself may give an explanation, and, what is more important, may give us hope for better things in the more or less distant future.

In the ancient world, the man who contributed most to the beginnings of science was unquestionably Aristotle. To him we owe the first comprehensive and systematic classification of human knowledge, a classification which for many centuries stood as the only encyclopedia of its kind. And Aristotle himself, through observation and experiment, made larger additions to the store of knowledge than any man before him or any that followed him for more than a thousand years.

But the very greatness of Aristotle gave such authority to all his words that his mistakes were perpetuated and they were a drag on scientific progress throughout the Middle Ages. He applied the syllogistic method to science, a method which is worse than useless when what is needed is a verification of the premises, as it lends to false conclusions an apparent validity. On such reasoning Aristotle discarded the atomic theory of Democritus, which came closer to modern conceptions of matter than did any contemporary theory. Because of a mistaken assumption regarding falling bodies, Aristotle reasoned that there could be no such thing as a vacuum.

Through the Dark Ages, Aristotle's method prevailed, without Aristotle's ability in applying it. Philosophers attempted to reach scientific truth by deductive reasoning from premises which often were religious dogmas. That brought religious intolerance into the field of science. Scientific arguments might lead to prison or to worse, as Roger Bacon and Galileo discovered to their cost.

But it was Galileo who ended for all time the dominance of the Aristotelian method, when he dropped his two weights from the tower of Pisa. In place of arguments about the "why", he substituted the study of the "how" by the experimental method, and, in establishing by experiment the law of falling bodies, he laid the foundation of modern science.

Many have been the differences of scientific opinion since Galileo's day, and we still have several with us, but the world of science has learned to look for their solutions, not in noisy debate, but in quiet laboratory experiment.

Not all the public has yet learned that lesson. Some still think the remaining problems of evolution can be settled by oratory in a country court house. Economics and sociology are less exact sciences than physics and biology, so that general public acceptance of recourse to experiment rather than to argument is hardly to be expected as yet in the political field.

We are still using in politics the methods of the Dark Ages. Political methods lag behind the technique of physical science by at least a thousand years. But there is manifested in some technically trained and eminent minds an apparent disposition to regard an important innovation in statute law as an experiment, to be tested in due time as to its results by a fact-finding commission, and that may be a hopeful sign.

Surely we have enough urgent problems in which governmental agencies may properly assist, such as the increasingly serious problem of technological unemployment, so that we should welcome in our politics any tendency toward resort to the scientific method instead of oratorical appeals to popular prejudice. L. A. H.

Contributions of Professor Elihu Thomson To Science and Engineering

By DR. KARL T. COMPTON
President, Massachusetts Institute of Technology

> *To honor Professor Thomson and his fifty years of service to industry, the Allied Service Clubs of Lynn (Mass.) tendered him a testimonial dinner and presented a large silver tray on September 27th. Several hundred of his friends and co-workers were present and many congratulatory messages were received. The principal address of the evening we present herewith.*
> —EDITOR

IT is a question whether genius is born or developed. Without going farther into this than to say that my own belief is that if it is not born it cannot be developed, we can at any rate see the evidences of genius in some activities of Professor Thomson's at a very early age, which were related to me as follows.

At the age of eleven, being prepared, though too young to enter high school (the entering age being 13), on the advice of his teacher, Elihu Thomson was kept out of school and allowed to read no books. His father obtained permission, however, to get for him several boys' books on scientific and mechanical subjects, and inspired by these young Thomson proceeded to construct for his own amusement a variety of the electrical devices which were the absorbing scientific interest of that day, such as batteries, Leyden jars, electromagnets, telegraphic instruments, etc. He constructed a frictional static machine out of an old wine bottle and when his father did not seem sufficiently impressed by the tiny sparks it produced, he went to work and constructed a large static battery which he demonstrated to his father so effectively as almost to lay him out.

This interest and genius, already evident at the age of eleven, has been equally evident throughout the long and wonderfully active career of Professor Thomson. Because of this he has been aptly called "the Dean of electrical engineers." He is the holder of more than 700 patents, which is the third largest number held by any living man. He is honored and respected by every scientific, engineering, and educational institution in the world and to come closer home, he is more than any other man responsible for the great electrical industry which supports approximately half the population of the City of Lynn and many thousands of people elsewhere. Commenting recently on Professor Thomson's contributions to the General Electric Company, Owen D. Young summed up the assets of the Company as $500,000,000, and with shares valued at $2,000,000,000. The difference in value between $2,000,000,000 and $500,000,000, said Mr. Young, is in a substantial part due to the ideas, inventions and spirit which this Company owes to Professor Thomson. It is seldom if ever that a man lives to see such a remarkable and tangible result of his life's work.

Electrical Inventions

Although his interests have been effectively employed in many lines, it is in the field of electricity that his genius has found its greatest scope and has led to the most important achievements and wide-spread service. It would be utterly impossible even to mention most of these discoveries, but I shall pick out just a few of those which have been outstanding. Perhaps the first great contribution was the invention, in about 1879, of the three-coil arc dynamo with its automatic regulator and other features, which formed the basis of the first successful electric-lighting system, which was put out by the Thomson-Houston Company in 1880, and which quickly found its place not only in this country but also in the leading countries of Europe. The machine was entirely automatic in its operation and so adjusted that it could maintain constant regulation in a system of many electric arcs, no difference how many of these arcs might be turned off or on. The need for such a regulator and its general nature were suggested to him by his earliest serious electrical studies, which were on the relation between the current and voltage in an electric arc and which led him to the discovery that as the current increases the voltage falls—a relation which accounted for the instability of electric arcs and pointed out the characteristics which a suitable control device must have.

It is interesting to note that this three-coil dynamo was a direct-current machine provided with a commutator, since in those days direct currents were more readily handled than were alternating currents and had certain advantages for arc-lighting purposes. However, exactly the same machine, simply with different connections, constitutes the three-phase generator which is so important in present-day electric power and was so represented in the original patent application. This is one of many cases in which Professor Thomson's ideas were years in advance of the world's readiness for their acceptance and utilization.

About two years later (1881) there was another great invention, that of a magnetically-operated lightning arrester. Although this was designed for the particular purpose of protecting his arc-light systems from lightning, it was the invention of a fundamental method of breaking electric circuits, which has found very numerous applications, one of the most important of which was by Professor Thomson himself in the control of electric trains.

The fundamental idea of this was again based upon an accurate knowledge and study of scientific phenomena involved in the discharge of electricity through gases. A transmission line, of course, has to be insulated from the earth by insulators adequate to prevent spark-over at the voltages used. If, however, the line is struck by lightning or an abnormally large electric surge passes through it, a spark may pass around the insulation, and it is a peculiarity of sparks through air that when once the insulation of the air is broken down by a spark there is literally no limit to the amount of current which can flow. Thus these sparks frequently cause short circuits or grounds of serious consequence.

Professor Thomson's discovery consisted in placing the insulator between the poles of a magnet, with the result that the spark or arc which might be produced was acted on by magnetic forces in such a way as to elongate it in the form of a bow which became more and more extended until it finally became so long that it went out. This principle is of just as great importance today as ever and is the foundation of many recently improved schemes for the switching of very large currents.

Again in these very early days and long before the importance of it was realized, Thomson invented the now universally used method of transmitting electric power, stepping it down from a high tension with the aid of a local transformer for consumption. This was set up as a working model at the Franklin Institute in Philadelphia in 1879, a patent was applied for in 1885, and after an unusually strenuous history in the patent office the fundamental patent for multiple-arc distribution systems with transformers, was granted in 1902. During this same time and as an additional safety device for high-voltage operation, Thomson patented the procedure of earthing the secondary coil of the transformer, a practice which has now become universal. In passing I should note here as an illustration of a notable characteristic of Professor Thomson, that this patent was dedicated on his advice by the General Electric Company to the public from a feeling that no patent or invention which has to do with public safety should in any way be restricted or made unavailable to the people.

In the further development of alternating-current machinery, he invented the constant-current transformer and the inductive regulator in which a movable secondary or primary coil could be adjusted to give constant-current output. Again in the direction of increasing the power capacity of transformers, in 1887–89 he first proposed the use of oil for cooling and for insulation purposes in transformers, and furthermore called attention to the great and deleterious effect of moisture in the oil, an effect whose full significance students of insulators are only now beginning adequately to realize.

I pass now to two of the most important and characteristic of Professor Thomson's discoveries. The first of these is that process of electrical welding whereby the welded surfaces were fused and united by the heat developed on account of the resistance in the contact between them. This method of welding has come into enormous use in industry and the indications are that it will be even more used in the near future. As examples in widely different fields may be mentioned the welding of seamless metal tubing, the attachment of filaments and other electrodes in incandescent lamps and vacuum tubes, and the fastening together of most of the parts of the new Ford automobile. In the former of these applications it may be interesting to know that a single manufacturer of bedstead tubing had manufactured, a few years ago, about 24,000 miles of such tubing by this process in a single year.

Again, one of Professor Thomson's most fundamental discoveries was the principle of dynamical repulsion between a primary and secondary coil. This can be demonstrated by a variety of interesting lecture experiments, most of which were suggested and shown first by Professor Thomson himself. One of these is an experiment which invariably arouses cheers in our freshman classes. A vertical iron core is surrounded by a spool of wire through which a large current can be passed upon throwing a switch. A metal ring which slips easily over this core is dropped around it from above. Immediately upon closing the circuit this ring is shot up into the air by the repulsive action by the electric current produced in the ring and the primary current in the coil. This scientific observation was developed by Professor Thomson into an alternating-current repulsion motor which is nothing more nor less than our ordinary induction motor, which is in almost universal use for small single-phase motors.

In connection with this discovery you will be interested in the following quotation from the *Electrical World* of May 28, 1887, commenting upon this work:

"It is, as yet, too early to assign to its proper place and limit the part which the alternating current will take in the electric arts. It has started on its career with most rapid strides, and it now only remains to devise means for its accurate measurement, regulation and distribution. Certain it is that Professor Thomson's brilliant paper cannot fail to act as a powerful stimulus to those whose attention is now absorbed in the direction indicated, and the fruits of which will soon be noted. We hope that at a later meeting of the Institute, Professor Thomson will give to the world his practical results, which he has only hinted at in the present paper." These practical results are now seen, for example, in probably a million induction motors now in daily use.

During the years 1885–1895 Professor Thomson was busily engaged with the development of electric meters of which more than 4,000,000 are now in operation. It is these meters which tell you and the Public

Service Corporation the amount of your monthly electric bill, and for this invention Professor Thomson was awarded the Paris Meter Prize of 1890 at a competition held after the Exposition of 1889.

As early as 1890 and continued intensively for half a dozen years thereafter were a series of brilliant experiments on high-frequency alternating currents, paving the way for many of the developments in wireless and other high-frequency applications which are being so actively applied at the present time. He constructed the first high-frequency dynamo, operating at frequencies of 30 to 40 times as great as any previously designed, and in connection with experiments with this type of electric power he designed also the first special high-frequency transformers. While working in this field he discovered a method of producing still higher frequency alternating current from a direct-current arc, by shunting the arc with inductance and capacity, thus discovering the method which played such an important role in wireless transmission up until its virtual replacement by electronic tube devices only within the past few years. This interesting method of producing alternating currents was actually applied to wireless telegraphy by Poulsen, and is therefore generally known as the Poulsen arc. Also in connection with these high-frequency investigations, he made the important discovery that the insulating power of oils at these high frequencies is very much greater than at the ordinary low commercial frequencies, if this insulating power is measured in terms of the path at which a spark will pass. Just one other item can be mentioned in connection with his high-frequency work, *viz.*, the fact that he discovered and was the first to use the method of tuning electric circuits, which is of course absolutely fundamental to modern electrical communication systems. This was done very early in his career while he was still a professor at the Boys' Central High School in Philadelphia, and was done in connection with experiments on wireless signalling which antedate the famous experiments of Hertz by about a dozen years, and as far as I have been able to ascertain constitute the first experiments on the propagation of electric waves and wireless signalling, with the sole exception of some experiments conducted still a dozen years previous to his by Joseph Henry in Princeton. These earlier experiments of Henry's were apparently never published but were used for the very practical purpose of allowing his wife to call him when his meals were ready.

Immediately upon the announcement of the discovery of Roentgen rays, Professor Thomson began a series of interesting experiments and valuable developments in connection with the x-ray art. The foundation for this work had been laid by previous experiments on electric discharge through gases at low pressures, and led to the first application of stereoscopic methods in Roentgenology only one year after the published announcement of the Roentgen rays themselves, and led also to various practical improvements in the design of x-ray tubes, as for example, the double-focus x-ray tube and a cooled-target tube within less than a year after the discovery of Roentgen rays. In connection with these experiments, Professor Thomson also took a lively interest in the physiological effects of x-rays including x-ray burns, and in the laws governing diffusion of x-rays by matter, subjects which have been developed on the one hand to exceedingly important applications in medical therapy, and on the other hand to give some of the most intimate knowledge which we possess of the internal constitution of matter, such as the arrangement of atoms in crystals and molecules, and the arrangement of electrons in atoms.

Other Interests

Thus far I have confined my remarks exclusively to Professor Thomson's activities in the field of electrical science, but you must not imagine that his interests were limited to this field. I shall have time only to mention briefly some of the more outstanding contributions which he has made to science and art in widely diversified fields. Jointly with his first colleague, Professor Houston, he invented and patented the centrifugal cream separator in the years 1877–1881. This was a device applicable to the separation of substances of different densities and has come into universal use in the cream industry, as well as in the laboratory and elsewhere, for centrifuging mixtures which it is desired to separate. A typical claim in this patent is this, "a process of creaming milk mechanically, skimming off the cream mechanically, and removing the skimmed milk mechanically, by centrifugal force." At that time Professor Thomson could not have dreamed that this same process of separating materials by centrifugal force would later be used by a brilliant young physical chemist of the Massachusetts Institute of Technology for separating the molecular ions of electrolytes and obtaining their relative weights.

In the field of steam engineering, Professor Thomson in 1899 produced a steam engine of remarkable efficiency which is now generally known as the "uniflow" engine. He described the principle on which this engine was based in the following words:

"The conditions are such that there is no retraversing the passages, no retraversing of even the cylinder portion. The steam enters, goes forward and out, keeps running steadily forward, so that we do not have any of those inter-actions that use up energy. We have a temperature gradient from one end to the other of steam cylinder."

Again in 1894 he devised a muffler for automobiles antedating the Maxim silencer and in many respects similar in principle. This muffler was based upon a sound scientific principle of dividing up an impulse or sound wave so that it should traverse a number of paths of unequal length, so that when these divided impulses all came together again they should be out of phase and partially neutralize each other so as to take away or spread out the shock of the initial impulse. I can only mention further in the field of automotive engineering that Professor Thomson devised numerous types of gas and oil engines, and of improvements in their construction.

In quite a different line of activity Professor Thomson's interest has continued unabated from the time quite early in his career, in 1878, when he published an account of a new method of grinding and polishing glass mirrors such as are used in telescopes, up to the present time when, as you all know, he has entrusted to his inventive skill the problem of constructing the largest telescope mirror ever undertaken, the proposed 200-in. reflector for the great new astronomical observatory to be associated with the California Institute of Technology and the Mt. Wilson Observatory, near Pasadena. This telescope mirror will have four times the area of the largest mirror hitherto constructed, and in order to give it the adequate strength and freedom from distortion under the influence of the heating by the sun's rays, it is planned to construct it of fused quartz. This is an optical engineering feat of such magnitude as to challenge the best scientific knowledge and inventive skill in the world, for it is a project of a different order of magnitude from any hitherto undertaken in this field.

As a background for this important undertaking, Professor Thomson has for a half-dozen years or so been perfecting a method of manufacturing fused quartz which has proved remarkably successful in permitting the construction of quartz apparatus by machinery, in size and quality hitherto unapproached. The quartz is melted in a specially designed electric furnace, is discharged and, solidifying under pressure, the small air bubbles always present in earlier quartz ware are compressed to such small dimensions as to be entirely invisible; thus a tremendous advance over the old-fashioned method of building up quartz apparatus by the individual work of a glass blower building on dab after dab of quartz under a blow-pipe flame. Quartz, besides making possible the great mirror, is also coming to be extensively used as a transmission glass for ultra-violet light in hospitals and in special lamps. It has also furnished the material making possible windows in deep-sea diving bells where its ability to withstand the enormous pressures has made possible deep-sea investigations of much greater depth than before.

In this great development and particularly that of the great astronomical mirror, we hope and believe that entire success will crown Professor Thomson's efforts and make possible a further investigation of the heavens at depths of space which are relatively as much greater than those now known, as are the depths of the sea now open to investigation greater than those which have hitherto been explored.

As my time is drawing to a close I cannot go further into details of Professor Thomson's various discoveries, but in order to give you some idea of their scientific and philosophical scope I am simply going to read the titles of various publications in fields which are quite outside any of those of which I have thus far spoken:

Change of Color Produced in Certain Chemical Compounds by Heat.
Inhalation of Nitrous Oxide, Nitrogen, Hydrogen, and Other Gases and Gaseous Mixtures.
On Recalescence in Steel and Its Relation to Expansion, Magnetization and Hardening.
Physiological Effects of Alternating Currents of High Frequency.
Thoughts on Cosmical Electricity.
Speculation Regarding Cause of Roentgen Rays.
The Nature of the Lightning Discharge.
The Nature and Origin of Volcanic Heat.
The Nature of Comets and Their Probable Relation to the Sun.
The Light of the Firefly.
A Hunt for a Great Meteor and Its Lessons.
Inferences Concerning Auroras.
Notes on the Moon.
The Heaviside Theory Valid.
Comments on the Coal Situation.
The Solar Eclipse of January 24, 1925.
Helium in Deep Diving.
A Suggestion or Hypothesis Concerning Zodiacal Light.

I hope that in this short address I have been able to give you an idea of the broad scope and fundamental importance in our modern industrial civilization of the work of this great scientist and inventor. More than any man now living, or in fact, more than any man in history, it seems to me that Professor Thomson has combined in a most remarkable way the constructive powers of the inventor, the thoroughness and soundness of the man of science, and the kindly balance of the ideal philosopher, teacher, and friend. Because of these qualities he is held in equally high esteem by engineers and in the most highbrow academic circles. He has always shunned publicity and because of this his achievements have not been highly advertised or made common objects of front-page newspaper publicity, but I think you will agree from this summary of his work that a fair appraisal of its importance, not only to this community, but to the industrial and intellectual interest of the entire world, demonstrates that the man whom we are met to honor tonight in every way deserves the tribute which was paid him by my predecessor and his friend, President Maclaurin, who said: "In his laboratory, built right into his house and an integral part of it, he is a man from whose mind probably thoughts on scientific problems are never wholly absent, an unselfish genius, well-trained, well-rounded, well-balanced man of science," or in the words of the *Electrical World* on the occasion of the awarding to Professor Thomson of the Faraday medal of Great Britain in 1927: "And how proud the electrical industry is of her Swampscott inventor, philosopher, and friend. Of all men living none except Edison has brought her so much honor and renown."

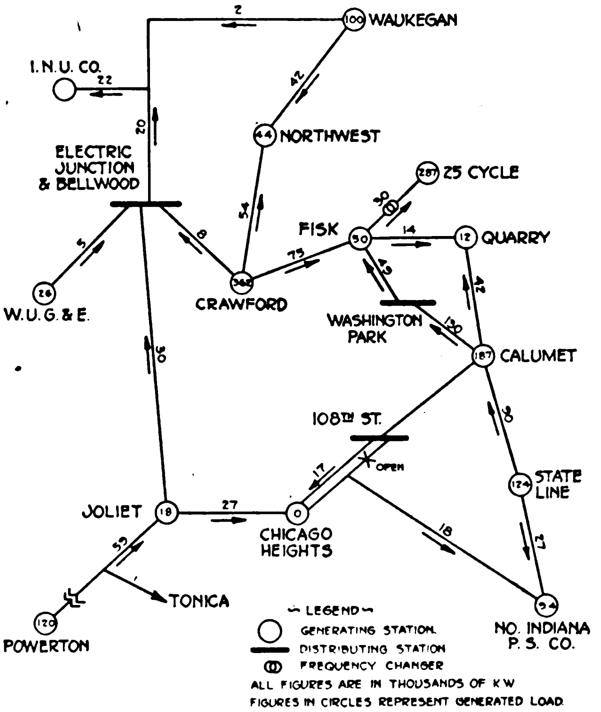
Power Flow Studies in Interconnected Systems

By P. B. JUHNKE

Chief Load Dispatcher, Commonwealth Edison Company, Chicago

> *Mr. Juhnke's article shows one thing not described in the text, namely, how great public utilities are providing for the needs of the public; not only the needs of today but how they prepare to meet future requirements.*—EDITOR

THE study of power flow in large interconnected systems is fascinating. For the purpose of helping such study, a series of diagrams were constructed for the Chicago District for different periods and seasons of the immediate years ahead, and for peak periods even a decade in advance. An interesting tale is connected with each, and a study of these diagrams imparts a keener understanding of the operating and engineering problems of the modern power system than any other kind of description.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27
53
TONICA
POWERTON
120
NO. INDIANA P. S. CO.
94
LEGEND
GENERATING STATION
DISTRIBUTING STATION
FREQUENCY CHANGER
ALL FIGURES ARE IN THOUSANDS OF KW
FIGURES IN CIRCLES REPRESENT GENERATED LOAD

Fig. 1. Power Flow Diagram for Peak Load Conditions on Friday, November 29th, 1929 at 5 p. m.

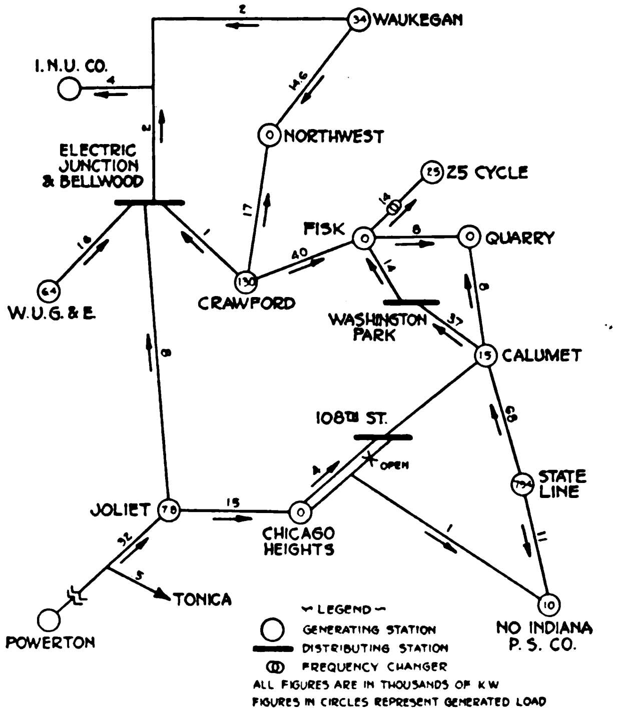

WAUKEGAN
34
2
I. N. U. CO.
4
14.6
NORTHWEST
0
ELECTRIC JUNCTION & BELLWOOD
25 CYCLE
25
14
FISK
0
8
QUARRY
0
17
40
16
W. U. G. & E.
64
CRAWFORD
130
WASHINGTON PARK
37
CALUMET
15
108TH ST.
OPEN
STATE LINE
JOLIET
78
15
CHICAGO HEIGHTS
0
32
5
TONICA
POWERTON
NO INDIANA P. S. CO.
10
LEGEND
GENERATING STATION
DISTRIBUTING STATION
FREQUENCY CHANGER
ALL FIGURES ARE IN THOUSANDS OF KW
FIGURES IN CIRCLES REPRESENT GENERATED LOAD

Fig. 2. Power Flow Diagram for Conditions on Tuesday, December 17, 1929 at 4 a. m.

The Chicago Regional System comprises the system of the Commonwealth Edison Company, operating in the City of Chicago; that of the Public Service Company of Northern Illinois, immediately contiguous to Chicago; the Northern Indiana Public Service Company, supplying the northwest section of Indiana, and the Western United Gas and Electric Company, supplying the Fox River Valley, with Elgin and Aurora as the principal cities. These four systems are operating as one system, by virtue of the Interchange Energy Contract, and comprise what is commonly known as the Chicago Regional System. Energy interchange across boundary lines of contiguously situated Companies is very free and all in accordance with the Interchange Energy Contract of 1925. This contract defines briefly that each Company shall receive credit for its reserve capacity beyond the average reserve capacity for the entire system, and likewise pay for its deficiency of capacity below the average reserve.

This contract but recently has received an important modification, in that operating costs outside of fuel cost are similarly paid for, so that in decisions to place load on stations of different Companies, only the relative fuel cost of the various stations is a determinant. In some of the diagrams and comments to follow, the effect of this contract upon joint obligations will be presented at some length.

The governing body of this contract is a Working Committee, consisting of two members from each Company, and the operating agency is the Operating Committee, consisting of one member from each Company. These two agencies have power to handle all billing and operating matters, respectively, and their agreements, having a large bearing on power interchange, will enter into subsequent considerations.

Fig. 1 is a diagram showing the power flow during last year's winter peak. Fig. 2 shows it during the early morning hours. Relatively the input of power into Chicago city territory during the winter peak is still small—only about 10 per cent to 15 per cent. The bulk of this comes from the Chicago District Electric Generating Station, formerly known as State Line Station, jointly owned by the Commonwealth Edison Company, the Public Service Company of Northern Illinois, the Northern Indiana Public Service Company, and the Interstate Public Service Co. The output of Powerton Station, likewise jointly owned, was absorbed by the Public Service Company of Northern Illinois in lieu of their share of the output of State Line Station. The billing, however, takes into account the respective shares of both the Public Service Company of Northern Illinois and the Commonwealth Edison Company of both Powerton and Chicago District Electric Generating Station, varying considerably in fuel cost. Waukegan, the Public Service Company of Northern Illinois water-front station, contributed about 50,000 kw. to the Chicago city peak load.

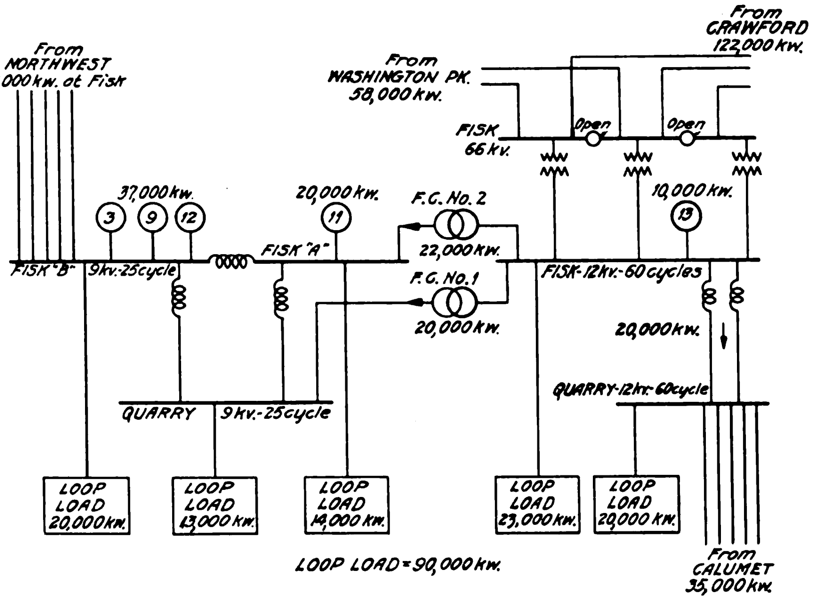


Fig. 3. Day Load on Fisk-Quarry (295,000 kw.)

Fig. 3 shows the power flow into the Fisk-Quarry Center in addition to what is generated there. This, incidentally, is the most important center on the entire system, on account of its being the source of supply to the all-important down-town district with its Edison 3-wire system. This district has not suffered a total interruption in service for almost thirty years, and it is not going to have one for at least another thirty years if painstaking design and operation can prevent it. Accordingly, both the 25 and 60-cycle systems are divided into sections, maintained with a view of limiting trouble and preventing its spreading to adjacent sections. This territory was originally all supplied by the 25-cycle system, but the development of the 60-cycle system has resulted in the older system being entirely overshadowed by the younger sister. The tie-in between the two systems is through two 40,000-kw. frequency changers, which receive energy from the 60-cycle system and deliver it to the 25-cycle system.

Fig. 4 shows the effect of the Commonwealth Edison Company increasing the load-factor of its load from Powerton Station, with the Public Service Company of Northern Illinois keeping its load-factor unchanged. Both Companies have equal rights to the major portion of the Powerton capacity.

The Powerton contract specifies that the operating charge to any Company for power received shall be an inverse function of the load-factor at which such power is taken. As the investment charges are fixed and cannot be modified, they do not enter into consideration.

On account of its very much larger system, the Commonwealth Edison Company was in position to avail itself of a far greater amount of night load than the Public Service Company of Northern Illinois, and this resulted in a decidedly improved load-factor. This required an operating agreement to be worked out by the Operating Committee of the Interchange Energy Contract, to the end that the Commonwealth Edison Company be given proper credit for the improved load-factor. The procedure was involved, owing to the fact that the output of Powerton to both Companies came over one set of lines terminating in the Joliet Station of the Public Service Company, from where a number of paths lead to the Commonwealth Edison Company—some very circuitous.

The output of Powerton to both companies had previously been governed by a schedule which provided for a monthly output to Commonwealth Edison Company and Public Service Company of

Northern Illinois of about 35,000,000 kw-hr. of which amount each Company was credited with one half.

It is obvious that a 50–50 division would no longer be fair during the hours from 10:00 p.m. to 6:00 a.m.

When the new schedule providing for the changed Commonwealth Edison load-factor was put in effect, the change on the power flow over the interconnection was most marked. The upper figures, alongside of each interconnection, give the daily output between 10:00 p.m. and 6:00 a.m. before the additional night load was put on Powerton; the lower figures show it after the change was made. The increased readings correspond very closely to a monthly increase of 6,000,000 kw-hr., distributed over practically all interconnecting elements.

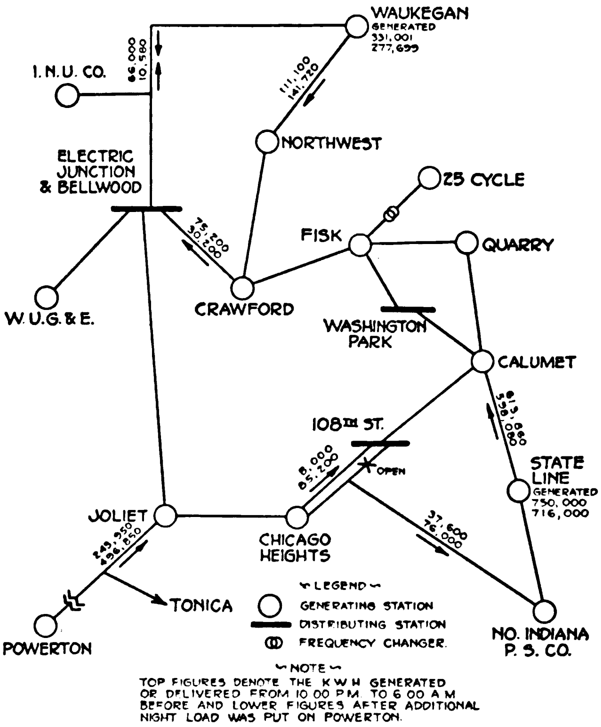

WAUKEGAN
GENERATED
331,001
277,699
I. N. U. CO.
86,000
10,580
111,100
141,720
NORTHWEST
ELECTRIC JUNCTION & BELLWOOD
25 CYCLE
75,200
30,200
FISK
QUARRY
W. U. G. & E.
CRAWFORD
WASHINGTON PARK
CALUMET
108TH ST.
8,000
65,200
OPEN
STATE LINE
GENERATED
750,000
716,000
JOLIET
CHICAGO HEIGHTS
37,600
76,000
249,950
496,850
TONICA
POWERTON
NO. INDIANA P. S. CO.
LEGEND
GENERATING STATION
DISTRIBUTING STATION
FREQUENCY CHANGER.
NOTE
TOP FIGURES DENOTE THE K W H GENERATED OR DELIVERED FROM 10 00 P M. TO 6 00 A M BEFORE AND LOWER FIGURES AFTER ADDITIONAL NIGHT LOAD WAS PUT ON POWERTON.

Fig. 4. Power Flow Diagram (See Text)

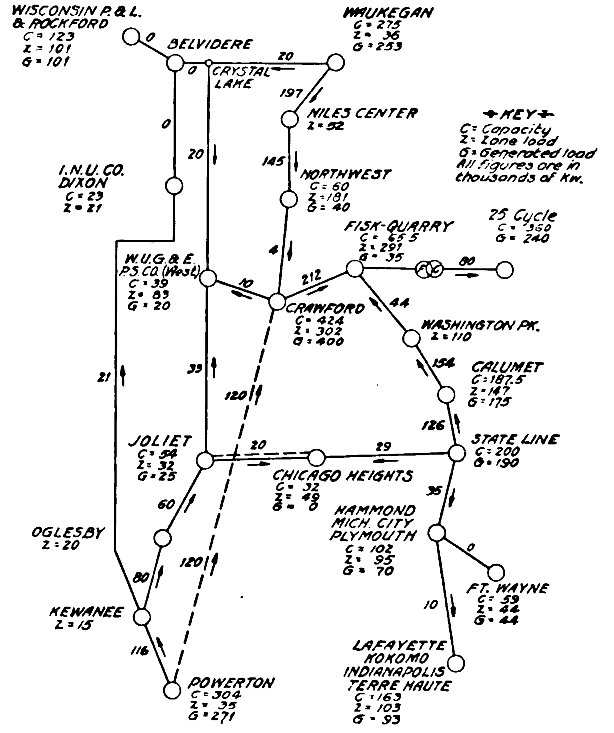
Specifically of interest is the Crawford-Electric Junction interconnection, on which output from Crawford decreased from 75,200 to 30,200 kw-hr. for the eight-hour period with the power flow before and after still opposite in direction to the Powerton flow. The Waukegan-Northwest interconnection, where an original input to Chicago of 111,100 kw-hr., due to generators at Waukegan, was brought up to 141,700 kw-hr. without increasing the Waukegan generated load, is also noteworthy. All these changes in readings constituted a rather fundamental change in operating set-up and required the accompanying agreement of the Operating Committee, which is of interest, as it definitely shows how unusual operating situations are dealt with under the Chicago Interchange Energy Contract.

MEMORANDUM OF AGREEMENT

Relative to Division of Powerton Output Between Commonwealth Edison Company and Public Service Company, and Billing Procedure to be Followed:

Whereas, up to and including December 15, 1929, the Powerton input to Joliet was equally divided between the Commonwealth Edison Company and the Public Service Company, and

Whereas, on the aforesaid date a new schedule was given to Powerton Station, calling for a considerable increase in the load of this station during the light hours of the morning, this additional load to be entirely furnished by the Commonwealth Edison Company in an amount exceeding 6,000,000 kw-hr. per month, and


WISCONSIN P. & L. & ROCKFORD
C = 123
Z = 101
G = 101
0
BELVIDERE
0
CRYSTAL LAKE
20
WAUKEGAN
C = 275
Z = 36
G = 253
197
NILES CENTER
Z = 52
KEY
C = Capacity
Z = Zone load
G = Generated load
All figures are in thousands of Kw.
0
20
145
I. N. U. CO. DIXON
C = 23
Z = 21
NORTHWEST
C = 60
Z = 181
G = 40
25 Cycle
C = 360
G = 240
FISK-QUARRY
C = 655
Z = 291
G = 35
80
4
W. U. G. & E. P. S. CO. (West)
C = 39
Z = 83
G = 20
10
212
CRAWFORD
C = 424
Z = 302
G = 400
44
WASHINGTON PK.
Z = 110
21
33
120
154
CALUMET
C = 187.5
Z = 147
G = 175
126
JOLIET
C = 54
Z = 32
G = 25
20
29
STATE LINE
C = 200
G = 190
CHICAGO HEIGHTS
C = 32
Z = 49
G = 0
60
35
HAMMOND MICH. CITY PLYMOUTH
C = 102
Z = 95
G = 70
OGLESBY
Z = 20
80
120
0
FT. WAYNE
C = 59
Z = 44
G = 44
10
KEWANEE
Z = 15
116
LAFAYETTE KOKOMO INDIANAPOLIS TERRE HAUTE
C = 163
Z = 103
G = 93
POWERTON
C = 304
Z = 35
G = 271

Dotted line indicates proposed addition this year.

Fig. 5. Diagram of Peak Load Conditions for Winter 1931–1932, Showing Loadings on Section Between Switch and Load Centers

Whereas, the object in view is an improved capacity factor for the load taken by the Commonwealth Edison Company, and

Whereas, further, the characteristics of the transmission network, with which both Companies are interconnected, result in this power being delivered to the Edison Company over routes not heretofore employed for this purpose,

Now, therefore, the following procedure shall be followed:

(1). From the input into Public Service Company over Powerton lines as metered at Joliet and Oglesby and designated by the symbol P there shall be deducted 6,000,000 kw-hr. as part of the Edison Company's share. The balance, $P-6{,}000{,}000$, shall be divided equally between the Commonwealth Edison Company and the Public Service Company, so that the total share of the Commonwealth Edison Company shall be $\frac{P+6{,}000{,}000}{2}$, and that of the Public Service Co., $\frac{P-6{,}000{,}000}{2}$.

(*a*). The billing of the Super-Power Company shall be, as heretofore, separate to each Company, and shall take into account the capacity factor of the load supplied to each Company, as determined from paragraph (1).

(*b*). Transmission losses between Joliet and Powerton shall be equitably compensated for.

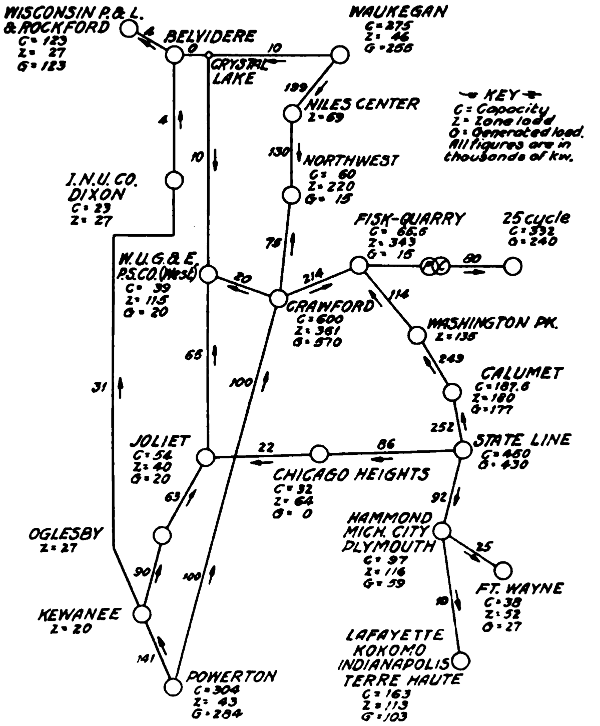

WISCONSIN P.& L. & ROCKFORD
C = 123
Z = 27
G = 123
4
BELVIDERE
0
10
CRYSTAL LAKE
WAUKEGAN
C = 275
Z = 46
G = 266
199
NILES CENTER
Z = 69
KEY
C = Capacity
Z = Zone load
G = Generated load.
All figures are in thousands of kw.
4
10
130
NORTHWEST
C = 60
Z = 220
G = 15
I.N.U. CO. DIXON
C = 23
Z = 27
FISK-QUARRY
C = 66.6
Z = 343
G = 15
25 cycle
C = 332
G = 240
78
80
W.U.G.& E. P.S.CO.(West)
C = 39
Z = 115
G = 20
20
214
114
CRAWFORD
C = 600
Z = 361
G = 570
WASHINGTON PK.
Z = 135
249
65
CALUMET
C = 187.6
Z = 180
G = 177
31
100
252
JOLIET
C = 54
Z = 40
G = 20
22
86
STATE LINE
C = 460
G = 430
CHICAGO HEIGHTS
C = 32
Z = 64
G = 0
63
92
HAMMOND MICH. CITY PLYMOUTH
C = 97
Z = 116
G = 59
OGLESBY
Z = 27
25
90
100
FT. WAYNE
C = 38
Z = 52
G = 27
10
KEWANEE
Z = 20
LAFAYETTE KOKOMO INDIANAPOLIS TERRE HAUTE
C = 163
Z = 113
G = 103
141
POWERTON
C = 304
Z = 43
G = 284

Fig. 6. Diagram of Peak Load Conditions for Winter 1933–1934, Showing Loadings on Sections Between Switch and Load Centers

(2). The Commonwealth Edison Company's share of Powerton input into Joliet shall be accounted for as follows:

(*a*). A part shall be considered as offsetting the Public Service Company's quota of the State Line output.

(*b*). Another part shall be considered as delivered at Chicago Heights, and equal to the net output of Lines 7701 and 2 compensated for transmission losses to Joliet.

(*c*). Recognizing the characteristics of a network, a part shall be considered as delivered at Northwest Station over the Waukegan interconnection. Such balance as is available, after allowing for parts described under 2(*a*) and 2(*b*), shall be considered applicable to the excess of this input over 17,000,000 kw-hr. per month, which is the quota now in effect for Waukegan input into the Edison system, and such part shall be corrected for transmission losses to Joliet.

(*d*). Another part shall be considered the amount of power, if any, which may be delivered to Crawford Station over the Bellwood interconnection. This to be adjusted for additional losses between Crawford and Joliet.

(*e*). The balance remaining undelivered to the Commonwealth Edison Company, if any, shall be considered delivered to the Public Service Company and shall be billed for at Crawford surplus energy rate, after being reduced for transmission losses from Joliet to the city limits of Chicago.

(3). The values of 6,000,000 and 17,000,000 kw-hr. stated in the foregoing, are subject to revision which may be necessitated by changes in the seasons, equipment outages, and other causes.

A great deal of interest attaches itself to the study of power flow some years ahead. Of course, such a study embraces the growth of load, the placement of capacity which, evidently, can only be assumed, but must bear a definite relation to the growth, and operating schedules such as are likely to be in effect at that time.

Fig. 5 shows the situation as it appears in 1931–32 and Fig. 6 as it appears to be in 1933–34, on the basis of capacity now authorized to be installed by that time. It is of interest to note that in the latter year about 30 per cent of the peak load of the Commonwealth Edison Company will be received in the city from stations without, while the output received from these stations at that time is estimated at about 40 per cent of total requirements.

These studies have been carried on for ten years ahead by a committee designated as the Committee on Intersystem Lines, functioning under the Load and Capacity Committee, but on account of the uncertainties surrounding the situation, largely due to the indefiniteness of capacity placements, they are omitted.

Such studies are very helpful in the planning of future developments and reflect favorably upon the foresight of an industry which looks far ahead in providing for the proper discharge of its obligation to the public and the territory it serves.

Welding Combined with Foundry Practice

By W. H. NAMACK and H. M. HOBART
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Ballston, N. Y.
Consulting Engineer, General Electric Company
Schenectady, N. Y.

IT is said in a recently published article that "Modern Chemistry is rejuvenating long-established industries and creating new ones over night." Yet it is not alone in chemistry but in many fields of science that knowledge is advancing at a rapid rate and new processes are being applied not only to the creation of new industries but to the further perfecting and advancing of long-established ones.

Modern welding processes constitute notable instances. It will be convenient to fix ideas by citing the electric arc welding process with which the writers have had occasion to become particularly familiar. Among the industries in which the arc welding process is already being employed with much advantage may be mentioned (1) steel building construction, (2) steel bridge construction, (3) ship building, (4) pipe line construction, (5) construction of various kinds of machinery such as machine tools, electric motors, generators, transformers, and switchgear, and (6) construction of pressure vessels.

There has been some feeling that the continually increasing use of welding is a menace to the foundry industry. The object of this article is to call attention to the industrial value of combining the accumulated experience in the foundry and welding arts, and of usefully applying this united experience to the development of the foundry art to a degree hitherto unattainable.

Vague fear that the steel foundry industry might be impaired, and an inclination to take ill-considered steps in anticipation of a decreasing need for cast-steel products, represent pessimistic views which have been taken of the rapid increase in the employment of welded rolled material in the place of steel castings. The present consideration shows that, instead of being regarded as a menace, welding processes should be considered as a logical complement to the foundry art.

During the last few years many kinds of dynamo-electric machinery have been redesigned, the castings employed in the former designs being largely (and often entirely) replaced by rolled material joined by arc welding. In the automobile industry and in the manufacture of other products, corresponding changes have been made. Although the practice of arc welding mild steel of the composition usually employed for ordinary steel castings is already highly developed and widely employed, engineers have to date seldom taken full advantage of designs whereby two or more component steel castings are joined by welding to make up larger parts. Similarly, steel castings are only infrequently welded to rolled plates and structural shapes.

For open-hearth foundries the cost of steel up to the stage of being poured into the mould is but little over one cent per pound, but the outlays incident to the further steps of producing castings bring up the cost of castings to ten cents or more for complicated products as against five cents to six cents per pound for those of simple design.

Now, any suitable number of simple and cheap steel castings, properly joined by arc welding, will be in every way as satisfactory as the usual single casting of steel. Indeed, shapes and features may be incorporated in a welded structure which, in a single casting, would be impossible in some cases and prohibitively expensive in others. As already stated, while complicated steel castings are often associated with costs of the order of over ten cents per pound, relatively simple castings made in large numbers may often cost between five and six cents per pound. In some cases the complications of making the product with a single casting and the limitations of casting processes, will result in the single casting having a greater weight for the required strength than would be the case with an equivalent structure made up from two or more simple castings, each devoid of expensive complications, welded together by the arc process. The designer must keep the cross-sections in his casting as homogeneous as possible, or make certain sections extra heavy to provide feeding and to minimize shrinkage stresses when the casting is cooling. For the same reason, he must also avoid sudden variations from heavy to light sections. These are but two of many limiting factors encountered in the design of castings.

An example can be a single complicated casting which weighs 1000 lb. and which can be assumed to cost ten cents per pound, or $100. An equally strong and satisfactory structure may be produced by welding together several simple castings costing, perhaps, only six cents per pound, and, owing to the greater freedom permissible in the design, it may have a total weight of only 800 lb., the total cost of the castings (before they are joined by welding) thus being only $48. For the purpose of the example, it can be assumed that the cost of joining the component castings by arc welding is $16. Then the total costs will be $100 and ($48+$16 =) $64 respectively, or ten cents per pound for the single casting and eight cents per pound for the joined one. The total weight has been reduced by 20 per cent and the total cost by 36 per cent. Unquestionably there are many cases where at the lesser cost a lighter and better product will be obtained. Also artistic appearance can in some cases be given more consideration with the joined structure.

Coming to the matter of large mild-steel castings weighing many tons, the practice of arc welding has now reached the stage where equally great strength may be obtained by welding together any number of castings of whatever size and shape correspond to the lowest cost. It is in very large castings that there is the greatest probability of blowholes, sponginess, and other defects, and that the cost and delay of rejections are most serious. The loss and delay in rejecting one or two small castings out of a considerable number is far less than that of rejecting a single large casting. Also, in cases where it will decrease the cost, the small castings can be machined on less expensive tools, several at the same time, and not welded together until all or a great part of the machine work is done. There is thus the hazard of rejection of only a relatively small part in the event of the development of any defect, with a decrease or elimination of delays. The time required to build machines employing very large parts may by this procedure be decreased considerably.

A large casting embodying many projections or changing contours involves a pattern which must be of such form that drawing of the pattern, position of the gate and feeding heads, etc., is at best a compromise made in the interests of the casting as a whole. As a result certain parts of the casting must necessarily suffer. If, instead of the large casting, we make the piece out of component castings, or even if some single part (which would be difficult if integral with the large casting) is made as a separate casting, then each part may be so moulded as to obtain the best results from feeding, etc.

The proposed procedure admits of the elimination of large and expensive cores and the avoidance of the difficulties associated with their use. The cost of cleaning and chipping will be reduced through dispensing with fins for the joining of core to core and to mould. All parts of the castings are more accessible for cleaning. Often cores must be dug out of small openings left in the casting for the purpose of vents and also for the removal of other cores, these small openings sometimes having no other purpose. Such openings must often be provided in a casting even though their presence is otherwise undesirable. Foundry troubles traceable to maintaining cores in proper position using "tie downs" to prevent floating, or chaplets for support, can be minimized by welding a separate casting to the main casting.

Another source of cost with large steel castings is the number of shrink heads and provision for their removal. Where a large steel casting of an original design is desired, it is very difficult to achieve the exact prescribed dimensions, owing to the varying resistance of the enclosed cores. In some cases it has been necessary to build the pattern and core boxes with a standard rule instead of using a shrinkage rule in order to obtain the proper measurements, this procedure making necessary certain trial castings to prove correctness of patterns. Shrinkage tendencies constitute very much less of a difficulty in small than in large castings. Furthermore, greater uniformity of composition may be obtained more readily in small castings.

Various desirable heat treatments can be applied to small castings, and much more cheaply and effectively than to very large ones. The employment of hydraulic pressure and also of centrifugal methods during the process of casting, to improve the casting, is more practicable and effective in small castings than in large ones.

Where edges of a component casting are to be joined to another casting or to a structural shape by arc welding, the pattern may be made so as to provide a V'd edge to facilitate the welding process.

In the case of very large structures, shipping may be expedited and cheapened by welding together only the smaller components into moderately large parts. At the place of erection, these moderately large parts may be welded together to constitute in turn the very large structure.

The kind of welding contemplated in these recommendations is so ordinary and is already so well-developed that, if taken over by a foundry, it would add but little to the burden on the executives. In other words, the foundry would continue to be a foundry, the welding work being a minor detail though one of much importance. In the case of a *new* foundry it would not have to be designed to produce individual steel castings above a certain reasonable size. This would decrease the cost of the foundry and of its equipment, thus decreasing the fixed charges. Perhaps the proposal may be made more definite by suggesting that, essentially, it consists in substituting for an outlay of 100 for a steel foundry of the traditional design for making castings up to a limiting weight of P pounds, a foundry equipped for making castings up to a limiting weight of only (say) one-fourth of P pounds and costing only 50 instead of 100, together with the provision of welding and machining facilities costing 10. With such a foundry, products may be supplied equivalent to those produced in the conventional steel foundry (but usually lighter and better) and with the overhead entailed by a capital outlay of $(50+10=)$ 60 as against the overhead entailed by a capital outlay of 100. Such a foundry may also take full advantage of electric furnaces producing superior metal under complete control at all times and free from the oxidations of the open-hearth process.

In arriving at the correct economic distribution of the work between the fabricating departments and the foundries, the use of arc welding for joining mild steel castings to each other, to rolled plates and structural sections, and to forgings and metal stampings, should be given more consideration than it is now given. Such use will likely prove to be as important as the arc welding of structural steel.

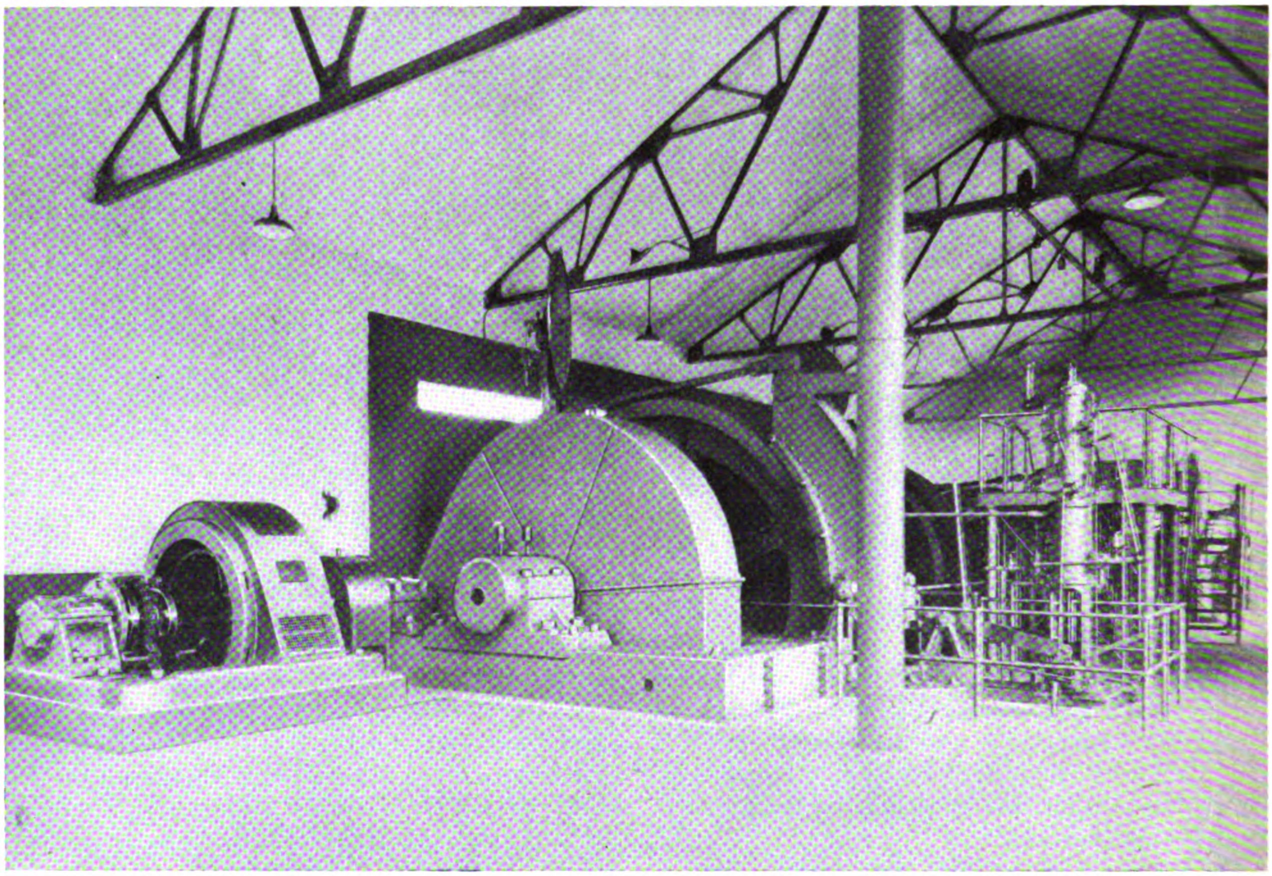
These suggestions apply *exclusively* to cast steel and *not* to cast iron. The welding together of cast iron parts is at present usually attended with complications and difficulties. Undoubtedly, however, the merits of the plan will often justify using cast steel where heretofore cast iron has been employed. This suggestion is the more appropriate in view of the recent improvements in the materials of cutting tools and in the technique of high-speed machining.

This general proposition of effecting savings by using small castings instead of a single large one, naturally leads to the possibilities of standardization and simplification of patterns and castings. In some parts of machines of very different kinds, sizes, and purposes, the same castings could be employed, suitably welded to other standardized castings, rolled shapes, forgings, or metal stampings to obtain the very different resultant structures corresponding to the machines of the different kinds, sizes, and purposes.

In addition to the lists of rolled shapes of standardized dimensions to which designers constantly refer in their work, there should gradually be accumulated lists of simple castings for purposes requiring their use in large numbers and which would be cheaply produced in large quantities. This should include various kinds of lugs and gadgets of cast steel or forgings, pressings, etc., so designed as to be ready to weld to other castings or to rolled sections or to plates or forgings.

A few cases have been observed where steel castings have been welded to other steel parts, but these are only isolated cases of a practice which could with much advantage be more widely employed.

An Unusual Mine Hoist



A 1500-hp. 360-r.p.m. 2200-volt 3-phase 60-cycle induction motor driving a shaft hoist in the Geneva mine of the Oliver Mining Co., at Ironwood (Mich.). The appearance of the installation and its surroundings is strikingly modernistic

Power-system Stability

A NON-MATHEMATICAL REVIEW

PART I

By R. D. BOOTH
Jackson & Moreland
Engineers, Boston

and

O. G. C. DAHL
Massachusetts Institute of Technology and
Jackson & Moreland, Engineers, Boston

FOREWORD

THE question of power-system stability has been discussed quite extensively during recent years and a number of papers on the subject have appeared in the technical magazines, especially in the *A.I.E.E. Journal and Transactions*. These papers, with but few exceptions, have dealt with the exposition of methods of analysis and have, therefore, been of a highly mathematical nature. The result of this fact is undoubtedly that only those directly concerned with the problem have read these papers in detail, while many others interested in the problem, but only indirectly connected with it, have been unable to readily get a general grasp of it.

The status of the stability problem today is such that methods of solution are quite well established and the problem as a whole is pretty well understood. It may be mentioned that the American Institute of Electrical Engineers is now giving attention to the standardization of terminology and definition of terms involved in stability work.

It should not be inferred from the above, however, that no work on the stability problem remains to be done. There are still questions open for investigation and research. The need for further analysis and experimentation along many lines was brought out at the meetings of the colloquium on Power-Circuit Analysis at the Massachusetts Institute of Technology, June, 1929. The following specific lines of investigation and publication of results were recommended (see *A.I.E.E. Journal*, August, 1929, page 648):

(*a*). A study of the effects of saturation in synchronous machines during transient conditions.

(*b*). Further information in regard to the performance of turbine governors under transient conditions.

(*c*). Further study of the conditions causing hunting in systems.

(*d*). Transient power limit tests on life-sized or actual systems and machines for determining the effects of important characteristics such as regulator characteristics, exciter speeds, constants of the amortisseur windings, and breaker time.

(*e*). Further information in regard to the characteristics of actual loads. This requires the development of methods of determining load characteristics.

(*f*). Further tests and the development of methods of calculating the impedance of circuits which include ground return.

(*g*). Further study of the value of different methods of system grounding from the standpoint of system stability.

(*h*). More complete and accurate records of system troubles, with all necessary data, including such as are obtained by automatic recording oscillographs.

(*i*). An investigation of the economic value of modifying generator reactance.

(*j*). Studies explaining the region of applicability and the relative accuracy of the various methods of analysis.

In view of the situation as it now exists it is believed that the time is opportune for a somewhat comprehensive and non-mathematical review of the stability problem. Such an article should particularly appeal to the electrical engineer who is not a specialist in this particular field, but who is interested in the problem and who would like to become acquainted with it and get a general appreciation of the factors which enter into it.

In the present article an attempt is made to fill this need. It reviews the general problem of power-system stability in the light of present knowledge. The article, however, also presents some aspects which still are in the controversial and unsettled state as, for instance, the effect of damper windings, and the influence of the various methods of grounding the high-tension neutral points. Possibly the comments on these items may be of interest also to those who have followed the problem more closely. These questions will undoubtedly receive further attention during the next few years.

GENERAL

Defining stability in a broad sense, it may be said that the stability of a power system is in general the ability of the system to operate intact in the steady state, as well as during disturbances.

The question of stability is, strictly speaking, not a new one. As long as alternating-current circuits have been in operation it has been definitely known that there is a limit to the amount of power which can be transmitted over a given line to a given load center. It has also been known that, with several synchronous machines tied to the same circuit, synchronism between these machines cannot always be maintained. So long as the alternating-current systems were small and comparatively simple, the problem of stability and the maintenance of synchronism was neither a particularly pertinent nor difficult one. The loads carried by these small systems were usually so low that normal operation hardly ever took place at loadings close to the critical conditions.

It is interesting to note that the question of system stability sprang to the foreground only a little more than half a dozen years ago. This was natural since superpower transmission was then first seriously considered. About the same time interest increased in the already-known fact that savings might be obtained by interconnections of independent systems; and this, coupled with the desire on the part of many companies to merge and carry through such interconnections, added still further to the interest in heavy power transmission systems.

For economic reasons the loads which must be carried by long-distance transmission lines *per se* today are large and the margin between maximum normal load and critical load-limiting conditions is often comparatively small. In designing such lines, therefore, it is essential that due consideration be given to the question of stability. Such lines must be able to carry successfully the maximum amounts of load in the steady state. They must also, and this is just as important, be able to survive numerous disturbances of a severe nature.

As already stated, interconnections between systems have recently been carried through quite extensively. The purpose of interconnections is, of course, to interchange power between the systems in such a manner that the maximum operating economy consistent with reliability of service is assured. Ordinarily this interchange does not call for very large blocks of power, and the tie lines—when designed on the basis of normal power transfer—may be comparatively light. However, in order to prevent the two systems from falling out of step during reasonable disturbances, line capacity must be provided to permit a sufficient transfer of synchronizing power over the tie line. This immediately implies that ties between systems should be designed, not only for the economic normal interchange power, but also to handle the required synchronizing power. In other words, the question of stability usually enters into the design of major interconnections.

Recently some of the distribution networks of the public-utility companies have grown to such dimensions that special measures have had to be taken, and special designs introduced, in order to ensure a maximum reliability. The most novel design is perhaps the networked a-c. distribution system involving separate feeders from the individual generators to the distribution transformers; paralleling and synchronizing the generating stations on the low-tension side of these transformers through the distribution network. In the layout of a system of this type it is, as a rule, necessary to check up to see that synchronizing power is adequate under normal, as well as fault conditions, and hence the problem of stability again enters into the picture.

In general, however, the stability situation as it presents itself in a metropolitan network is considerably less serious than it is in connection with isolated stations supplying power over long-distance transmission lines.

Every operating engineer realizes that it is a prerequisite to maintain operation with as few interruptions as possible. Consequently it is entirely logical that in the design of the systems proper attention be given to all factors which affect the operating reliability. It is then easy to appreciate the great importance of giving thorough attention to the stability of modern large alternating-current systems.

ANALYSIS OF THE PROBLEM

As already stated, two kinds of stability must be considered, namely, (1) *steady-state or static stability*, or stability during normal operating conditions, and (2) *transient stability* or stability during disturbances.

Steady-state Stability

An examination of the steady-state stability of a line involves computation of the maximum power which can be transmitted over the line in question during the steady state. The maximum power is also termed the steady-state or static power limit, and is usually calculated at specified terminal voltages of the line or for specified field-current conditions in the synchronous machines. The static power limit is not characteristic of and dependent upon the line alone, but also depends upon the size and characteristics of the systems to which the line is connected at its two terminals.

The problem which often presents itself in long-distance transmission is the following: An isolated station—for instance, a hydro station—transmits power over a long trunk line which at the receiver end ties in with already-existing power-transmission or distribution systems. Usually a number of already-existing generating stations feed power into the latter, and loads are taken off at numerous points. It is beyond the scope of this article to outline in detail the methods by which the steady-state stability of such a system should be calculated. Let it suffice to say that methods for this purpose are now fairly well established, although each individual problem as a rule gives rise to certain modifications and offers a chance for additional ingenuity on the part of the engineers handling it.

Again referring to the specific system cited above, it is necessary in such an analysis to take into account not only the characteristics of the line itself and its terminal transformers, but at the sending end the effect of the generators must be properly introduced, and at the receiving end the effect of the characteristics of the transmission and distribution circuits in the receiving system, as well as the effect of the stations and loads, must be taken into account. It is not an easy matter to introduce properly the effect of a complicated receiving system. As a rule assumptions must be made and approximations resorted to. If these are judiciously made, however, it ought to be possible in any particular set-up to simulate with sufficient accuracy the actual effect of the systems at the receiving end of the transmission line.

The principal factors entering into the problem will now be enumerated and treated briefly.

(*a*). Generator Design and Reactance

The circuit parameter which especially limits the amount of power which can be transmitted over a system is the reactance. It is advantageous therefore, from the standpoint of stability, to employ generators with low reactance. This is the equivalent of using generators with a high short-circuit ratio.

The short-circuit ratio of most generators of normal design lies in the neighborhood of unity. In hydro machines the diameter is usually ample, due to the hydraulic requirements, to permit a design combining unity short-circuit ratio with high efficiency. Because of the inherent character of the design problems involved in high-speed turbine-generators, however, it is common experience to find in such machines of normal design short-circuit ratios slightly below unity. This results in minimum cost and best efficiency for machines of this type.

Generators of special short-circuit ratio requirements mean increased costs and a sacrifice in efficiency, especially in connection with turbine machines. Turbine-generators deviating appreciably from standard design, therefore, are seldom encountered. Usually, since the steam units as a rule are more intimately associated with the load areas while the hydro units frequently represent the total amount of synchronous machinery at the sending end of a long transmission line, the need for short-circuit ratios higher than normal is much less for turbine-generators than for hydro machines.

In recent hydro-electric installations where the question of stability has been an important factor short-circuit ratios exceeding unity have been employed. The Conowingo generators, for instance, have a short-circuit ratio of 1.33, while those selected for the Fifteen Mile Falls Development have a short-circuit ratio of 1.25.

Even though a high short-circuit ratio and a low reactance may not be essential from the standpoint of stability in a given system layout, they may be desirable in order to prevent self-excitation of the generators when switched onto a transmission line whose receiving end is free. With the increasing size of generating units, however, the charging-current requirements are likely to be of continuously decreasing importance as a factor influencing the selection of short-circuit ratios.

One drawback associated with low reactance is, of course, that short-circuit currents and the duty on circuit breakers will be increased. Furthermore, special low-reactance machines will have greater first cost, greater size, and therefore greater installed cost and in general lower efficiency than machines of standard design. The selection of proper generator reactance in any installation, therefore, usually rests upon a compromise.

The shape of the saturation characteristic of the generator also has a certain bearing on the stability of the system. By accentuating the saturation and operating normally well above the knee of the magnetization curve, some improvement in stability may be obtained. This is comparatively slight, however, and although this feature was discussed some years ago in connection with schemes for the improvement of stability it is no longer considered of particular importance.

(*b*). Line and Transformer Reactances

Large high-voltage power transformers usually have a reactance of from 10 to possibly 16 per cent. This reactance cannot easily be reduced by change in design. Furthermore, in cases involving long-distance transmission the part which the transformer reactance contributes to the total system reactance is ordinarily comparatively small, so that a minor reduction in transformer reactance would be of little practical importance.

The line reactance in a long-distance transmission line is usually of major importance. It is an inverse function of the number of circuits employed, the size of conductor and the number of circuits usually being selected on the basis of adequacy for transmission of the desired power and consideration of the economics involved. The spacing, on which the reactance primarily depends, is mainly governed by mechanical considerations and by the operating voltage. The result is that any line designed on the basis of proper economics has a very definite reactance which cannot be changed unless an additional circuit is introduced.

It should not immediately be concluded, however, that the addition of one or more circuits will improve the situation as far as stability is concerned. In considering the long-distance high-voltage transmission line it is necessary not only to take into account its reactance, but also its distributed capacitance. Additional circuits, owing to this capacitance, will call for additional charging current, which will affect the operation of the generators in such a manner that their excitation will be reduced. Reduced excitation reduces the stability and as a consequence of this fact the addition of circuits, even though justifiable economically, would beyond a certain point be detrimental instead of beneficial from stability considerations. It is interesting to note here that usually the reactance of the line itself is not the most important one on the system. Much more reactance, as a rule, is associated with the terminal apparatus, and these, therefore, contribute to the limitation of the power which can be transmitted more than the reactance of the line itself does. (See Fig. 1.)

(c). Synchronous-condenser Size and Reactance

Almost universally a synchronous-condenser installation will be found at the receiving end of a long transmission line for voltage regulation and power-factor correction. Sometimes the line is also sectionalized and in such cases there may be condensers installed at the sectionalizing points.

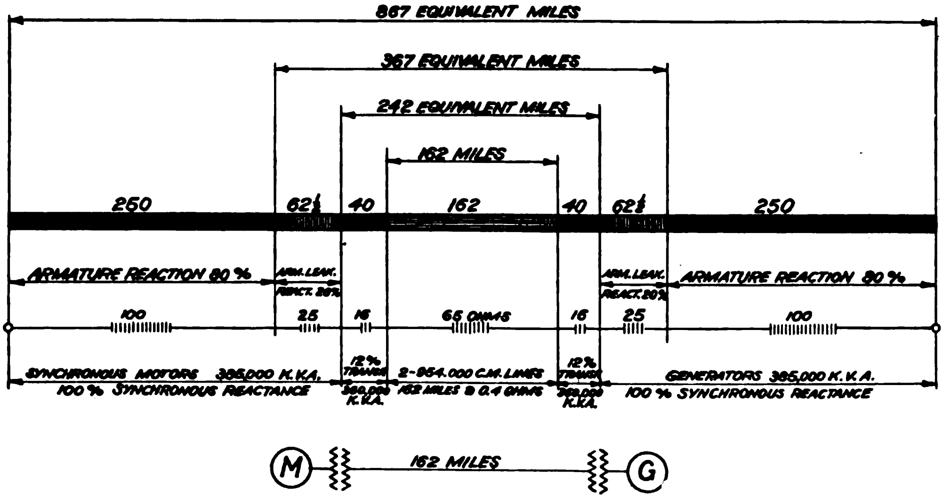


Fig. 1. Division of Reactance Between Elements of a Simple Transmission System

The stability of the line is affected by the size and hence by the reactance of the synchronous-condenser installation. It is desirable in a condenser to obtain a maximum amount of change in reactive power with a given change in terminal voltage. As the terminal voltage drops the reactive power which the synchronous condenser draws will increase in a leading direction. This is beneficial in that it tends inherently to counteract the change in voltage.

When the reactance of the condenser is low this change in reactive power for a given change in terminal voltage is larger than when its reactance is high. It may also be mentioned here that a more effective change in reactive power is obtained when the condenser operates over-excited, *i.e.*, at a high field current.

The effectiveness of a condenser as a stabilizing agent also depends to some extent upon the shape of its magnetization curve much in the same manner as was previously mentioned for the generators. When operation takes place high up on the magnetization curve a somewhat larger change in reactive power, with a certain change in voltage, will occur than when operation takes place at a lower point on the magnetization curve. This agrees with the statement just made in regard to the benefits of operating over-excited.

The previous statements regarding the advantages of low-reactance synchronous condensers should not be interpreted to the effect that installation of specially-designed low-reactance machines is generally advocated. Such special condensers are bulkier and more expensive than those of standard design. The question, therefore, is largely one of cost involving the balancing of the benefits estimated to be derived from the use of special condensers against their additional cost. It is believed that standard condensers would be selected in all but very exceptional cases, and that it in general would be good economics to purchase such machines rather than to call on the manufacturers to deliver condensers of special design.

(d). Load Characteristics

The characteristics of the actual loads—or of the equivalent load by which the action of the individual loads is often simulated for purposes of calculation—are important and may materially affect the operating stability. The usual commercial load is made up of three types; namely, synchronous, induction, and lighting load. These have individual and rather typical power voltage and reactive-power voltage characteristics. The resultant characteristic of the aggregate load depends upon the percentage it contains of each type. As a rule, it will be found that the total power decreases somewhat with voltage and that the reactive power which usually is lagging at normal voltage will decrease (*i.e.*, change in a leading direction) as the voltage decreases. Usually the percentage change in the reactive power is larger than the percentage change in active power. As a consequence of this the power-factor is somewhat improved when the voltage drops.

(*e*). Voltage-regulator and Exciter Characteristics

The schemes used for voltage regulation have an important effect on the stability under normal operating conditions. It is desirable that the voltages at the points where control is applied be kept as nearly constant as possible. For instance, if it were possible to keep, say, the high-tension voltages at the sending and receiving end of the lines absolutely constant for all conditions independent of the supply of active and reactive power to and from these buses (*i.e.*, if these buses were "infinite" buses), the power limit of the system would be equivalent to that of the transmission line alone and be limited only by the line characteristics. This is just mentioned as an example. In practice it would be a hopeless task with the present control systems to accomplish this end.

With suitable voltage regulators and excitation systems, however, it is possible to reduce the effect of the reactance in the machines which the regulators control. The amount of reduction in effective reactance so obtained depends upon the type of regulator used as well as on the speed of response of the exciter and its ceiling voltage. The standard automatic voltage regulator benefits the system only to a very small extent as regards its static stability. The power limit which will be obtained with strictly constant excitation in all synchronous machines will not be appreciably modified by the use of this regulator.

With the recently developed "high-speed" regulators, however, the situation is considerably changed. With these regulators the voltage build-up of the exciter is limited only by the characteristics of the exciter itself, and with exciter designs permitting a high build-up rate, the change from one exciter voltage to another may take place very rapidly.

A high-speed regulator used in conjunction with an exciter having a reasonably high inherent build-up rate associated with an appropriate value of ceiling voltage will materially improve the power limit of a system under normal operating conditions. The amount of improvement depends upon the exciter response rate and the ceiling voltage. Experiments have indicated that the power limit increases comparatively rapidly with exciter speed up to a certain limit (1) of the latter. This upper value is quite moderate and it is apparently not at all necessary to go to excessive exciter build-up rates with their attendant expensive exciter designs and increased switching duties in order to benefit fully during normal operating conditions by the improved regulator characteristics.

It is thus seen that with suitable voltage-regulating and excitation equipment the power limit during normal operating conditions can be increased. It is well to emphasize at this point that with a system operating near this limit it is in a state of dynamic equilibrium. In order to remain in synchronism it definitely relies upon the proper action of regulators and excitation systems. If these fail to perform in their normal manner the system will no longer be able to carry the power in question, and instability will result.

To what extent it is appropriate to rely on regulators for maintenance of stability during normal operating conditions is largely a matter of judgment. It is felt that at the present stage of development it is not advisable as a rule to operate in the region of dynamic stability. It is more conservative to keep the system below the actual static power limit (*i.e.*, the one corresponding to constant field current in synchronous machines) under normal operation, and even though high-speed regulators and excitation systems may be installed, to rely on these only when strictly necessary to ascertain the transmission of power under emergency conditions as, for instance, when the transmission capacity of the line for some reason or other is impaired.

It is not improbable that further developments in the voltage-regulator field will result in the production of a regulator which will be so reliable and satisfactory in all its operating aspects that it may definitely be relied upon to maintain continuous operation under conditions of dynamic stability.

(*f*). Effect of Voltage Grading

Sometimes long-distance transmission lines are operated at a somewhat higher voltage at the sending end than at the receiving end. This may give rise to more economical operation and necessitate less expensive condenser installations. The grading may have some effect on the static power limits, although it may be said that with a reasonable amount of grading this effect, as a rule, is rather insignificant.

(*To be continued*)

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[1] Quotation of specific values is purposely omitted since as yet no definition of exciter response is standardized.

The Constant-air-weight Method of Cupola Blowing

PART II

THE OPERATION OF CUPOLAS AND THE EQUIPMENT FOR SUPPLYING AIR BY WEIGHT

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Charging

COKE CHARGES. Coke charges should be uniform in volume or weight from start to finish and should be kept level. If the coke is stored in the open it is necessary to charge by volume, checking the volume by weight of dry coke at frequent intervals. Baskets or boxes should be used for handling materials as they will give more consistent charging than using an ordinary coke fork. It is much preferable to store the coke in a dry place and use scales for weighing each charge.

The weight of the coke charges depends on the weight of the iron charges. Starting with a 10 to 1 ratio of iron to coke between charges this ratio can be increased and less coke charged each day, thus gradually securing a much higher ratio.

Experience indicates that at least a 10 to 1 ratio, exclusive of bed, can very readily be secured; and with a few tests, ratios of 12 or 14 to 1 can be secured. A number of foundries are now running with ratios this high, and melting very hot iron and at a high rate.

Iron Charges. The iron charges should be uniform in weight from beginning to end of the charging process, the weight varying in proportion to the diameter of the inside lining. Roughly, the weight should vary from 1000 to 4000 lb. per charge, using 1000 to 1500-lb. charges up to 42 in. diameter, 1500 to 2000 lb. from 42 to 54 in., and 2000 to 4000 lb. from 54 in. up.

Flux Charges. Excepting rare cases, ordinary limestone is entirely satisfactory as a flux, and the amount of charge should vary from one to three per cent depending on the amount of scrap and the conditions of the material charged into the cupola. Enough should be charged to keep the slag running freely, as it is necessary to remove the slag as fast as it is formed in order to keep the cupola in the best of operating conditions.

Height of Charges. Increasing the height of the charging door will give the gases a better chance to give up their heat to the descending iron charges, but at the same time causes more coke in the upper charges to be burned before reaching the bed. There will also be more lining to be heated and, therefore, greater radiation. Hence, placing the charging door over 15 ft. above the bottom will not much improve the efficiency. Higher charges also require higher pressure in order to force the gases through the additional resistance.

Air Charges. Using a constant weight of air, trial runs should be made on the cupola starting on the basis of a 30-in. bed, 10 to 1 ratio between charges, and 26.8 lb. of air per min. per ton of iron per hr. This presupposes good coke, no leakage of air in pipe line or gates, and normal leakage around the wind box and tuyeres.

The iron should come hot and at the normal rating of the cupola. The cupola should then be run on this basis for a few days in order to make sure that satisfactory operation can be secured under these conditions. The amount of coke should then be reduced to give a ratio of 10.5 to 1 and the air reduced to 26.4 lb. of air per min. per ton per hr. If results are satisfactory after two or three days the cupola may be run with 11 to 1 ratio and 26.0 lb. of air, then 11.5 to 1 and 25.6 lb., and finally 12 to 1 and 25.3 lb. of air. Beyond this point practically no change in the air will be necessary, and further improvements will come from reducing the coke charges and possibly the bed charge.

In case it is necessary to start with a low ratio, and possibly a high bed, and to work up gradually, the first step of course is to have the proper mixture of iron. Since a large amount of air, although it may give a high melting rate, may affect the chemical analysis, temperature, freezing point, and strength of the iron, it is much better to start with a small amount of air, as given in Table I and gradually cut down the coke in the charges as well as the bed as long as improvement in the operation is secured.

General Operating Problems

Iron Cold or Cooling Quickly. The appearance of this difficulty is due to the bed having probably burned out too much at the start. At the first indication that the iron is cooling, the air should be reduced approximately 25 per cent and held at this point until the iron again becomes satisfactory, which indicates that the bed has again built up; the proper amount of air can then be supplied.

When the iron is coming cold or burnt, a remedy in the past has been to add more coke; but cutting the air will eliminate the difficulty, although the melting rate may be lowered. Using too much coke or too little air is safe, and with the automatic control giving a constant weight of oxygen at all times consistent results can be secured day in and day out. By working for a balance of bed, coke charges, and oxygen, a great improvement in the coke ratio can be made.

Iron Melting Too Slowly. Two causes of this difficulty with appropriate remedies may be conveniently listed thus:

> (1). Bed is probably too high at the start. Hence the air supply should be increased considerably and maintained at the higher rate long enough to burn out the excess bed.
>
> (2). Air leakage is too great, in which case leakage should be reduced or the amount of air supply increased.

Slow melting is a result of having too much coke in the bed and in the charges, or not enough air. By cutting the coke, good hot iron will be secured and the melting rate can be increased. In one case it was stated that the cupola was melting only 12 tons per hour when the rate was supposed to be 16 tons. An actual check showed the blower had been shut down 24 times during the ten-hour run and, upon making due allowances for the fact, the actual melting rate was found to be 16.5 tons per hour. In spite of all the shutdowns the iron was hot all day long and one shutdown was for 50 min.

Under good operating conditions the maximum tonnage rating of cupolas, as specified by the manufacturer, can be obtained and even exceeded under the best operating conditions.

Iron Melting Too Fast. If the iron is melted entirely too fast at the maximum rating, the cupola should be lined down to give the proper rate in order to secure the best efficiency. If, however, the rate is somewhere near what is desired, the cupola can be regulated satisfactorily by shutting the blower down to stop the melting. Deducting the time the blower is shut down from the elapsed time will give the proper melting rate. The number of tons melted in any given hour will depend on the time the blower is operating. When the blower is shut down the slag should be running, indicating that the reservoir is full of iron; the tap hole is then bodded up. The cupola can thus stand from 30 to 45 min. On starting again the iron should be almost as hot as before because little heat is lost if the iron is kept inside the cupola. Holding the hot iron keeps the cupola in good condition and no detrimental effect in the operation should appear.

High Wind-box Pressure indicates too high an amount of air or bridging around the tuyeres. With the correct amount of air the wind-box pressure should be from 10 to 12 ounces and not over 16 ounces. The air should be reduced and the tuyeres should be built as previously described. The iron in the reservoir should be kept near the tuyeres and the slag kept running at all times. The hot iron, being nearer the tuyeres, keeps the region around the tuyeres hotter and reduces the building up of slag and iron into a cold ring at this point.

Excessive Consumption of Brick is due to the use of too much air. A lessening of the air will diminish both the number of bricks required and the work necessary to repair the cupola each day.

Slag hole burning out is due to excess air, resulting in a high wind-box pressure and a failure to maintain the iron high enough in the reservoir to keep the slag running all the time.

Effects of Pressure

Before proceeding to the proper method of control, reference should be made to the part the air pressure plays in the melting operation. In some cases the practice has been to hold constant pressure on the wind box, but this is entirely wrong, because the resistance to the flow of air through the cupola is not constant and, therefore, the pressure on the wind box should vary to maintain a steady air pressure in the cupola. The volume, also, varies according to varying temperature and barometer; and the pressure on the wind box must be increased to force a greater volume through the cupola. Pressure bears no relation to the operation other than being the means of forcing the proper amount of air or oxygen into the cupola. However, it is well to remember that for large cupolas additional pressure must be available in order to force the air through the tuyeres at the higher velocity required to carry it into the center of the cupola and to overcome the greater cupola resistance due to the higher charging doors. If a cold spot is forming in the center, this means that the air is passing up around the side and is not penetrating the charge, in which case the height of the tuyeres should be cut down. Then, of course, a higher pressure is required to force the same amount of air through the effective area. This increases the velocity of the air and it penetrates further into the cupola.

Smaller tuyeres and higher charging doors probably account for only one or two ounces increase in the wind-box pressure. However, making the tuyeres smaller, giving a better penetration, may possibly extend the zone of slag formation at the tuyeres further into the cupola and bring the wind-box pressure up another ounce or two.

In the summer time, when a larger volume of air is required in order to get the same weight of oxygen, the wind-box pressure should be higher, but with warmer air the slag formation may be less and, therefore, little change would be noticed in the wind-box pressure in seasonal variation from winter to summer. In any case, the wind-box pressure should be normally around 10 to 12 ounces and perhaps in some cases as high as 16 ounces.

A wind-box pressure of 12 ounces means that, for the particular amount of air being forced into the cupola, 12 ounces pressure is needed to force it through; it is interesting to note just where the pressure drop occurs.

There are very few installations where more than one ounce pressure is needed to force the air from the blower through the pipe to the wind box. The wind box is usually large and the length of the path the air has to travel is very short, so that the loss in pressure is almost negligible. The tuyere openings usually have a combined area of somewhere near the area of the cross-section of the pipe from the blower, and as the length of the path through the tuyeres is very short there is something less than an ounce pressure drop through the tuyeres. As previously stated, five-inch tuyeres have been plugged up with brick so that they were only half this size; hence, blowing the same amount of air through in both cases into the cupola without any charges, the wind-box pressure was increased from something less than an ounce to slightly over one ounce. It is safe to say with the right amount of air flowing that never more than two ounces of pressure is required to get the wind from the blower outlet through the pipe, wind box, and tuyeres to the contact point with the coke. At this point the pressure required is increased several ounces as a result of the air cooling the dripping iron and slag and forming a ring through which the air has to be forced.

Fig. 5 shows the wind-box pressure at the moment of starting the blower as 0.3 lb. or about five ounces. Assuming two ounces drop to the contact point of air and coke there is left only three ounces to force the air through the bed, the first charge of melting iron, which may tend to soften and fuse together with the limestone and slag, and then on through the successive layers of coke and iron.

After about eight minutes the pressure was up to eight ounces and the iron and slag were dripping by this time. Thirty minutes later the pressure had become three-quarters of a pound.

It would seem safe to generalize from these data that, two ounces being required up to the contact point, the difference between this pressure and the initial pressure of five ounces, *viz.*, three ounces, is required to force the air the rest of the way when no iron or slag is forming at the contact point. In the next eight minutes the pressure goes up to eight ounces probably because the iron, starting to get soft, is fusing with the slag and stopping up some of the openings.

Afterward, the iron and slag start to drip and freeze around the tuyeres; thus during the next 30 minutes the pressure rises to 12 ounces.

The pressure drop, therefore, is distributed after the first hour of operation as follows: two ounces to contact point; four ounces through contact point; three ounces through bed and layer of melting iron, and three ounces through the successive layers of iron, coke, and limestone, a total of 12 ounces.

METHOD OF CONTROL OF AIR

What has been said up to this point demonstrates the fact that the best results in the melting operation depend not only on having the weight of iron and coke under complete control, but the weight of air also. Therefore, the next step is to introduce an apparatus and a method of controlling the weight of air supplied to the cupola.

For this purpose the General Electric Company has developed a certain electrical control system which is connected with the line supplying current to an electric motor operating a centrifugal compressor with suitable characteristics. This control operates an artificial restriction placed in the pipe between the blower and the cupola. This compensates for changes in cupola restriction, as well as for changes in atmospheric conditions, so as to maintain a constant weight of air flowing at all times. Any change in the resistance to flow through the cupola, or any change in the atmospheric temperature or pressure, is automatically compensated for, so as to maintain the same weight of air per minute, regardless of the changes mentioned.

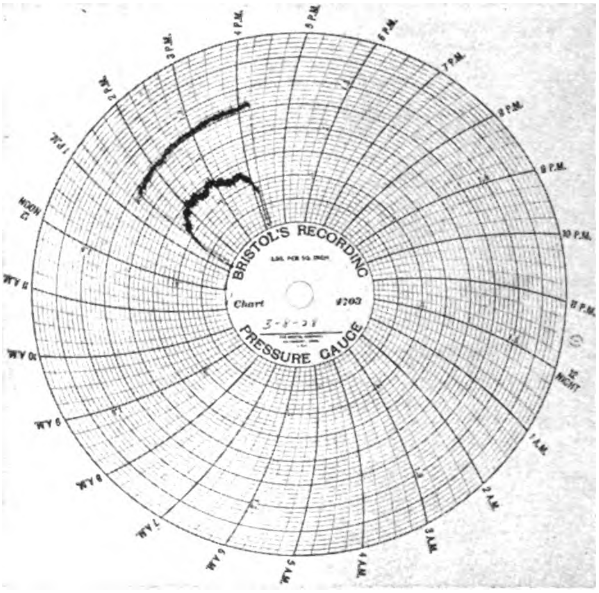


Fig. 5. An Actual Chart of Compressor Pressure (Outer Curve` and of Wind Box Pressure (Inner Curve in Tests of a Centrifugal Blower with Automatic Control Holding Constant the Weight of Air Delivered to Cupola

Control Equipment

The electrical control system operates on the principle that a blower and motor of suitable type have such characteristics that constant weight of air is delivered when the electrical input in kilowatts is maintained constant. The apparatus consists of a blast gate supplying an artificial restriction in the line, which is so manipulated as to give the motor input the desired constant value. This manipulation may be done by hand through the use of an ordinary hand-blast gate (Fig. 6) and meter (Fig. 7), or it may be done automatically by a mechanism to be described later, thereby eliminating the personal equation.

As stated, the apparatus is actuated primarily by the power input to the motor. However, in ordinary cases, voltage is fairly constant, so that the current reading in amperes varies directly with the power input. This current reading may therefore be used in most cases instead of the kilowatt reading.

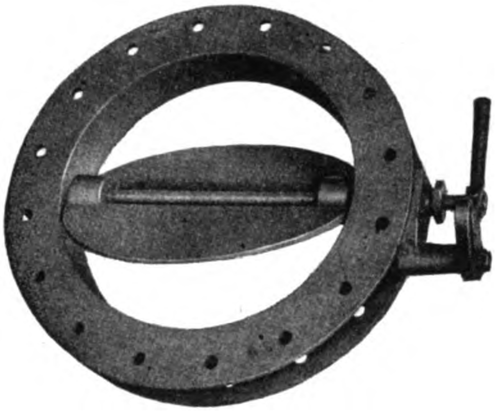


Fig. 6. A Manually-operated Blast Gate

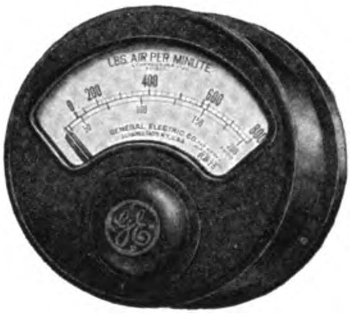


Fig. 7. A Specially-calibrated Meter for Indicating Weight of Air Supplied to Cupola

The automatic control equipment shown in Fig. 8 consists of a reversing motor geared to a blast gate through a high gear ratio and provided with limit switches to prevent the gate from over-traveling. The control panel (Fig. 9) is mounted with a contact-making ammeter, an indicating ammeter calibrated in pounds of air, switch and fuse, regulating rheostat, and three standard contactors.

When the current increases slightly, contact is made and the circuit is completed through one of the contactor coils. The contactor closes and supplies power to the motor, rated at approximately 1/25 hp., causing it to run in the proper direction to close the blast gate, bringing the current down to normal again. Likewise, when the current falls slightly, the other contactor closes, running the motor in the other direction, thereby opening the gate, bringing the current up to normal again.

The third contactor is energized all the time the blower and motor is running, and power for operating the panel is supplied through its contacts. When the blower is shut down at the end of the heat, this contactor drops out and an auxiliary contact closes the power circuit to the panel, so that power flows direct to the closing contactor and the gate moves to the closed position and the limit switch on the gate breaks the circuit. Thus provision is made for automatically closing the blast gate at the end of a heat. The gate should be closed at this time to restrict the flow of gas from the cupola to the pipe line and to be ready for future starting.

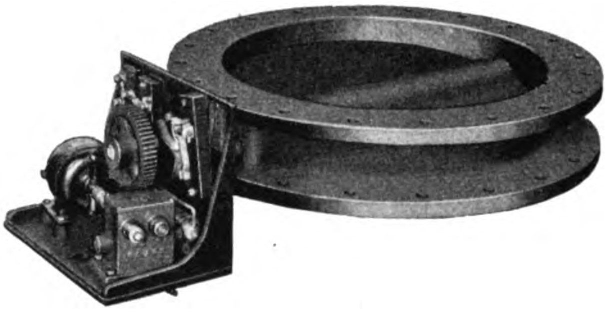


Fig. 8. Operating Mechanism for an Automatically-controlled Blast Gate

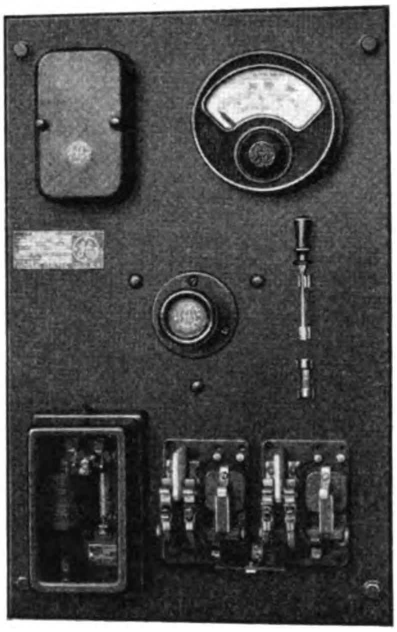


Fig. 9. Control Panel for Constant-weight Cupola Blower

The rheostat is used to vary the current through the ammeter so that any desired weight of air can be maintained within the limits of the blower, which is approximately from 30 per cent of normal load to 20 per cent overload. The contact-making ammeter arm is adjusted to the horizontal position by screws and a spring; and for a given current, corresponding to the normal current of the machine, with the rheostat in approximately mid-position and in parallel with the coil on the contact-making ammeter the arm will float in this position with both contacts open. If the current or "pounds of air" value is to be increased, some of the resistance is cut out, allowing more current to flow through the rheostat and less through the current coil. This causes one of the contacts on the arm to close and the blast gate is opened wider, increasing the flow of air. The increased flow of air increases the current to a value which causes the contact to open and the arm returns to the horizontal position. The new value of current and the corresponding new weight of air are indicated on the indicating ammeter. To reduce the weight of air, the rheostat handle is turned in the opposite direction and the resistance increased. This causes the other contact on the arm to close, which in turn closes the gate and reduces the weight of air to the lower value required.

The equipment is made up of standard parts, properly enclosed, and requires no attention other than oiling of the small motor and gears probably once or twice a year.

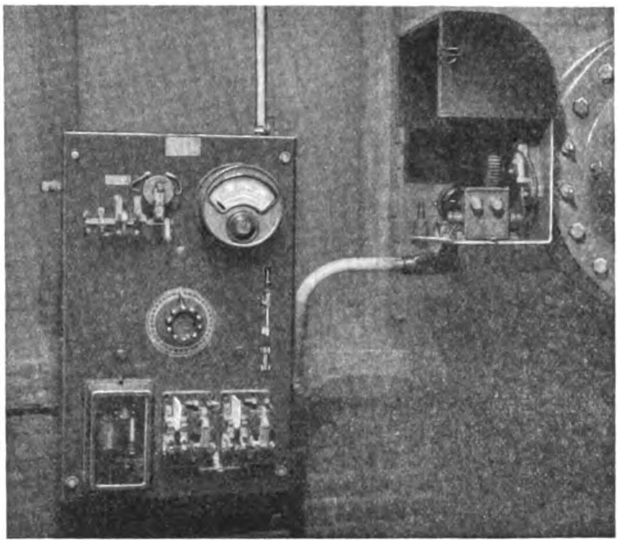


Fig. 10. An Installation of Automatic Blast-gate Equipment for Supplying a Constant Weight of Air to Cupola

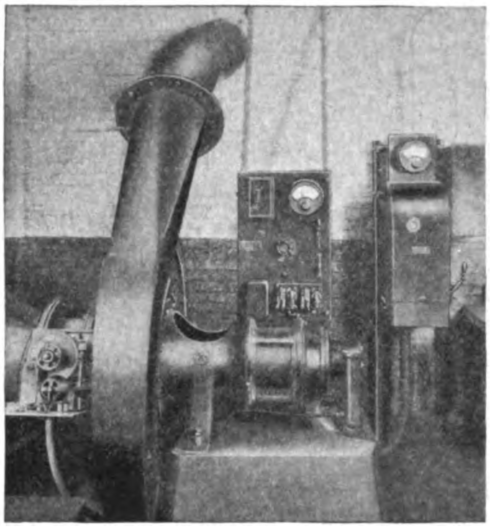


Fig. 11. A Complete Installation of Blower, Motor-driven Blast Gate, Automatic Panels, and Hand Starter for Blower Motor

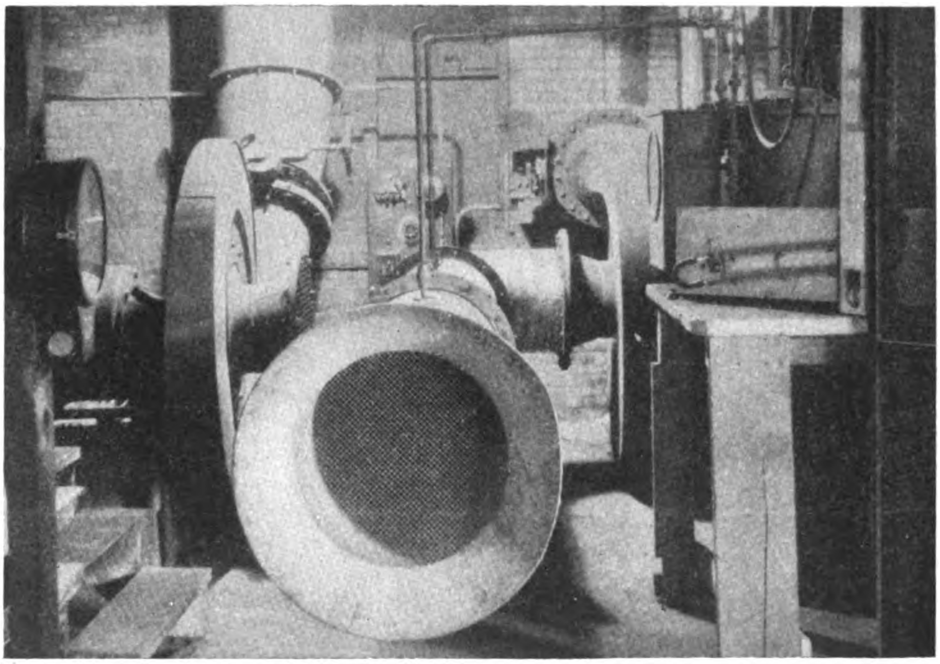


Fig. 12. A Complete Installation with Additional Special Testing Apparatus

Fig. 10 shows an installation of one of the control panels and gates.

Fig. 11 shows a complete installation of blower, motor-driven blast gate, automatic panel, and hand starter for the blower motor. Fig. 12 shows an installation of a complete equipment with special testing apparatus. Figs. 13 and 14 show other installations.

Blower Characteristics

The control equipment just described is suitable only for use with blowers having certain definite characteristics. Fig. 15 shows the characteristics of such a blower, and it can be shown from these curves that constant power input, or constant current, will give constant weight of air.

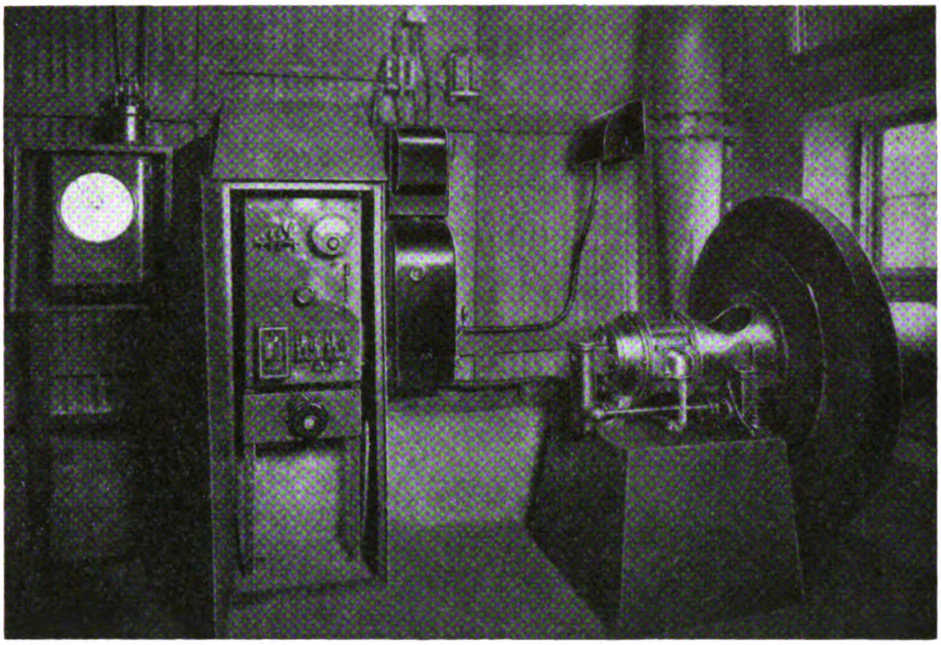


Fig. 13. A Complete Installation with a Graphic Recording Meter

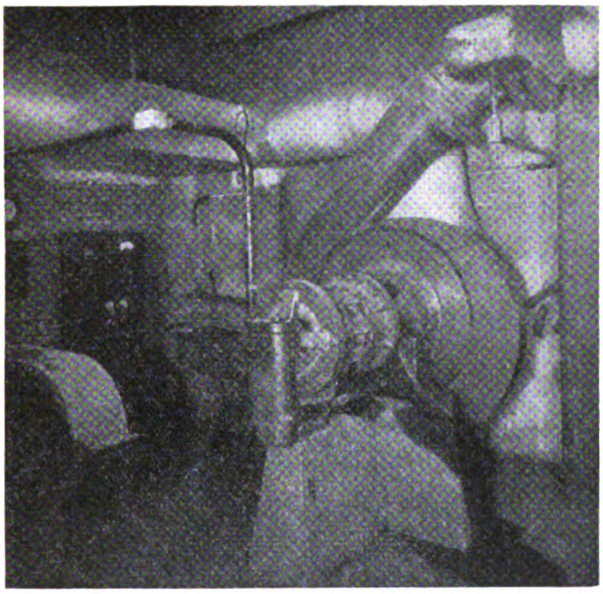


Fig. 14. A Typical Installation of Automatic Cupola Blower Equipment

As an example, let us assume for a certain condition that 7000 cu. ft. of air is required at 60 deg. F. and 14.7 lb. per sq. in. to give the proper weight of oxygen. When the air temperature increases to 100 deg. F., the air will have expanded so that the volume of inlet air should be increased in order to get the same weight. Since the weight of the air varies inversely with the absolute temperature, we require $\frac{560}{520}\times 7000 = 7550$ cu. ft. of air to give the same weight as before. Likewise, when the air temperature drops to 0 deg. F. we need only $\frac{460}{520}\times 7000 = 6200$ cu. ft. to give the same weight of air. This shows an increase of 22.0 per cent in the volume from 0 deg. to 100 deg. in order to maintain a constant weight of air.

Referring to Fig. 15 it is found that the input for 7000 cu. ft. for the 60-deg. condition is 48 kw. (58 hp.). For 6200 cu. ft. at 0 deg. F. the input is again 48 kw.; and likewise for 7550 cu. ft. at 100 deg. F. the input is still 48 kw.

This shows conclusively that by holding a constant value of kw. input for a machine having characteristics of this nature, a constant weight of air will be delivered irrespective of changes in temperature, barometer, or altitude, or resistance through the cupola.

Results Obtained

As a demonstration of the fact that this equipment will hold a constant weight of air for varying conditions, tests have been made with recording instruments; and practical results of over two years' operation have unquestionably proved its worth.

The upper curve in Fig. 16 shows the iron temperature taken with an optical pyrometer. The consistently high temperature of the iron should be noted. This is, of course, the result desired, and once the proper combination and distribution of coke, iron, and air is determined it can be maintained day in and day out and consistent results will be obtained.

The atmospheric temperature curve in Fig. 16 shows a drop in temperature around 3:30; and it should be noted at this time the inlet air volume curve started to fall, but the weight of air did not change.

With the proper lubrication, there is little opportunity for wear of blower or motor-driven blast gate, and wear on the automatic control is no greater than that usually experienced with contact-making mechanisms. The predetermined weight of air is thus maintained at all times and within close limits, and this factor which has been so hard to determine and control in the past is now automatically controlled, so that all the attention can be given to maintaining the coke and iron in the proper relation.

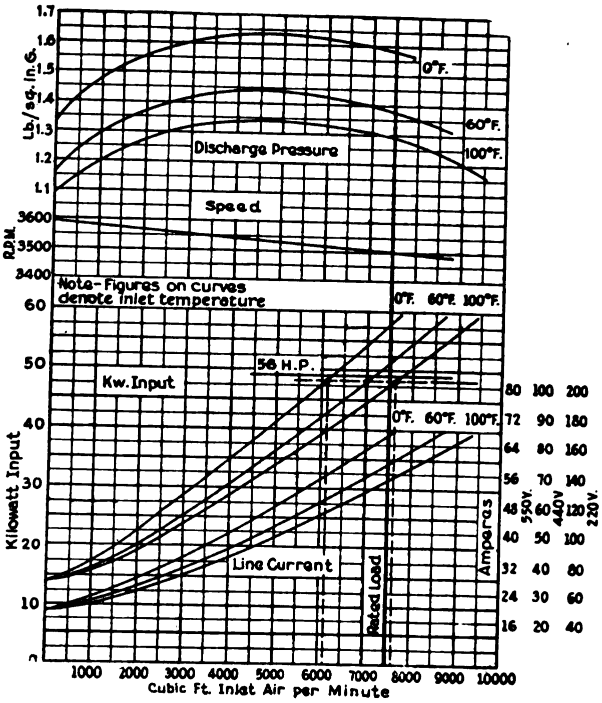


Fig. 15. Blower Characteristics Required for the Automatic Supply of a Constant Weight of Air to Cupola

When a change is made in the lining diameter of the cupola the weight of air can be changed to suit the new operating conditions and, likewise, if a different kind of coke having more or less fixed carbon is used, the weight of air can easily be figured and the equipment reset to give this amount, and the best operating conditions again secured.

If during any certain run it is felt that a greater or less weight of air is required immediately, the equipment can be set in a few seconds to increase or decrease the weight of air as required.

Additional features can be added to the standard equipment shown in Figs. 8 and 9, such as a lock to prevent anyone but an authorized person tampering with the control, an auxiliary meter located at cupola to indicate the weight of air being used, or a recording meter located on the panel or at the cupola to give daily records of weight of air.

In all cases the parts used are simple and of standard construction and will give indefinite service.

Mathematical Theory and Résumé of Automatic Cupola Control

Certain centrifugal compressors or blowers, driven by substantially constant speed motors, have characteristics such that within the range of normal operation the effect of increase of volume and of atmospheric conditions on the electric power input is such that the power input varies only with the weight of air. This weight is found by multiplying volume by the existing density, which is determined by atmospheric conditions. Such a compressor requires a given

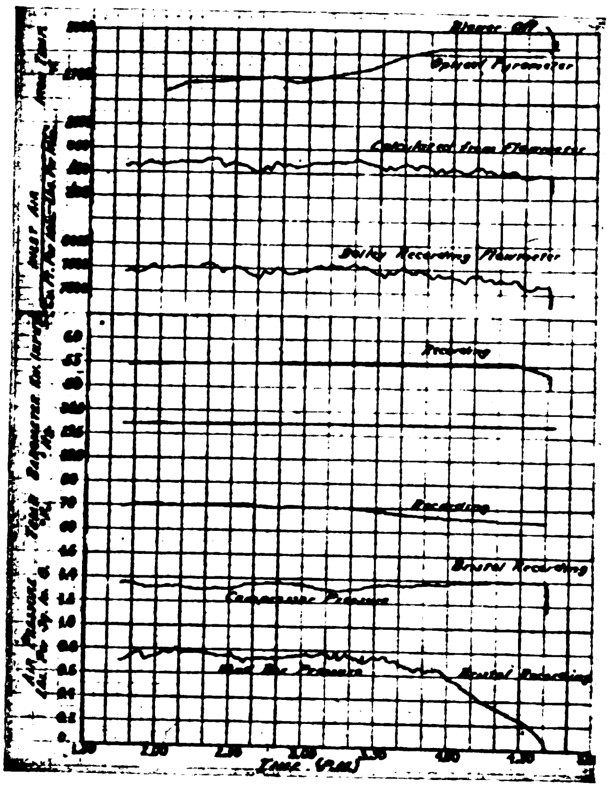


Fig. 16. Typical Performance, from Graphic Recording Meter Chart, of a Cupola Supplied with a Constant Weight of Air

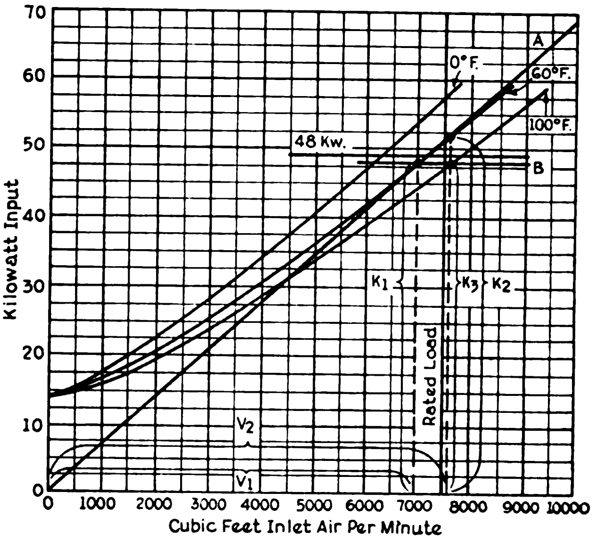


Fig. 17. Performance Curve Showing Straight-line Relationship Upon which Constant-air-weight Theory is Based

power input for a given product of volume times density, regardless of the individual values of these two factors; thus the power input varies in the same ratio as the weight of air. Therefore, if operated at constant input to the driving motor, the weight of air delivered by such compressors will be held constant within close limits irrespective of changes in the atmospheric temperature, barometer, or resistance through the cupola.

The characteristics of a typical blower were shown in Fig. 15. Now, taking the kilowatt input curves (Fig. 17) it will be seen that a straight line A can be drawn coincident with the full-load region of the curve and that it passes through the origin. With such curves it may be easily shown that this machine will deliver a definite weight of air per unit time for each reading of wattmeter, regardless of atmospheric temperature, barometer, or altitude.

Assume for one condition a power input K_1 and a flow of V_1 cubic feet of air at a value of inlet density D_1 (for 60 deg. F.) and a second condition where the values are K_2 and V_2 and the density is the same as the original density D_1. Then, since the power curve in the region in which we are working practically coincides with a straight line through the origin, we have

$$\frac{K_2}{K_1}=\frac{V_2}{V_1} \tag{1}$$

Suppose now that at the second point the density is not the original value D_1, but has another value D_3 (at 100 deg. F.) such that the weight of air passing through the machine will be the same as the weight at the original point where the inlet volume is V_1. With constant weight, density and volume are inversely proportional, hence

$$\frac{V_1}{V_2}=\frac{D_3}{D_1} \tag{2}$$

The power at the second condition when the density was D_1 had the value of K_2. If, however, the density is D_3, the power K_3, which varies directly as the density, will be given by

$$\frac{K_3}{K_2}=\frac{D_3}{D_1} \tag{3}$$

This is true, regardless of the efficiency or shape of efficiency curve, since we are working at a given value of inlet volume and hence at a given efficiency. It follows from Equations (2) and (3) that

$$\frac{K_3}{K_2}=\frac{V_1}{V_2}$$

From the Equation (1) it follows that

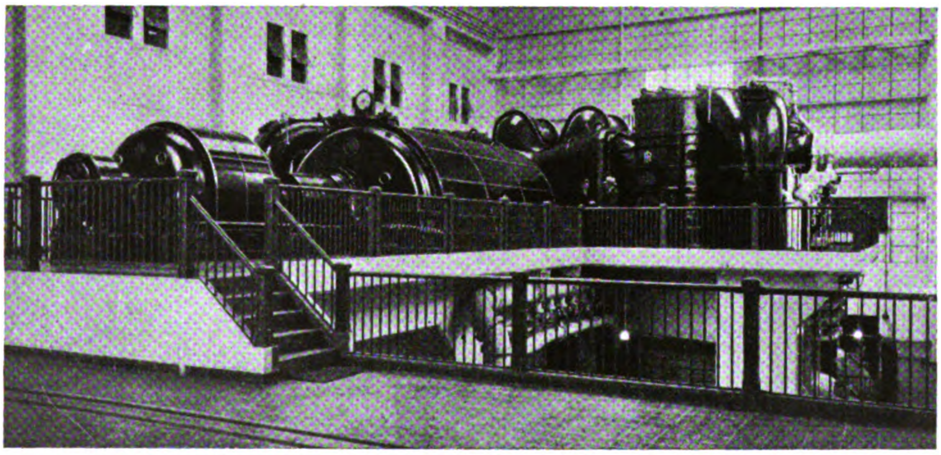
$$\frac{K_2}{K_1}=\frac{K_2}{K_3}$$

Hence, $K_1=K_3$

An iron foundry cupola may be provided with a constant weight of air by manipulating the blast gate or throttle valve in the blower discharge line. The cupola pressure will vary from time to time and it is therefore necessary in laying out a blower for an iron foundry cupola to arrange the pressure slightly higher than would be needed for average operation, and to throttle the difference with the blast gate. Then if atmospheric conditions, density of the coke or iron, changed conditions of the tuyere, or anything else tends to increase or decrease the weight of air supply so as to change the wattmeter reading, the flow can be restored by manipulation of the blast gate.

Varying the opening of the blast gate simply inserts or removes restriction to the flow of air, thereby maintaining a definite restriction in the system, so that a fixed quantity will flow for a given condition. If the conditions of temperature or barometer change, the blast gate assumes a corresponding position, and the proper air flow is assured.

(Concluded)



90,000-kw. Turbine-generator in the Long Beach Plant of the Southern California Edison Co.

Short Cuts to the Solution of Floodlighting Problems

Comments Upon the Scope and Trend of Modern Floodlighting—Data for the Computation of Floodlighting Installations—Sample Problems—Typical Installations—Summary of Requirements

By H. E. BUTLER
Illuminating Engineering Laboratory, General Electric Company

FLOODLIGHTING is no longer a new art. Its many and diverse applications are now serving the purposes of beauty and utility in all parts of the country. Great buildings of every type are revealed in all their architectural beauty during the night hours, when the greatest number of people have opportunity and leisure to see and appreciate them. Public monuments and private estates are artistically illuminated by concealed projectors, and electric fountains draw thousands nightly to admire the play of rich colors on ever-varying jets and spouts of water.

The application of floodlights to office buildings, hotels, banks, theaters, and factories has also established a new and dignified method of publicity that identifies the structure with the purpose for which it is used and conveys its message at a time when the building would otherwise be lost in the dark.

In more utilitarian aspect, floodlighting is being widely applied to freight classification yards, where it protects property from damage and theft, and operators from accident; to billboards, signs, filling stations, parking areas, and real-estate developments, in all of which night advertising is of special importance; and to construction work and dock operations.

In the world of athletics, floodlighting has worked a revolution. It has established baseball as an evening sport in scores of cities and made it substantially profitable by reason of the added attendance. Many football fields have been floodlighted for night practice and for games, while track events, hockey, and trap shooting are winning favor as evening sports thanks to the perfect illumination provided by floodlighting projectors.

This widespread response to the efforts of engineer and manufacturer has brought about a high degree of standardization in design and method. Since the introduction of the art, when in 1915 the first notable use of floodlighting was made at the Panama-Pacific Exposition, exterior illumination has been steadily developed to meet the constantly increasing applications—architectural, commercial, and industrial. Projectors and equipment, in various types and for different sizes of lamps, now meet every requirement in the floodlighting field.

Projectors of the latest types possess the advantages of minimum maintenance and the highest efficiency resulting from the use of heat-resisting clear and colored lenses and silvered-glass reflectors with copper protective backing. Three types of lenses are in use. Clear lenses are of four designs—plain, lightly stippled, heavily stippled, and with wide-angle distribution in any one plane; colored lenses are either plain or heavily stippled. For projectors equipped with clear lenses, two sizes of color plates—red, amber, blue, or green—can be used effectively. Reflectors are interchangeable in projectors of the same size and are of glass, silver-plated and protected by copper backing. The use of glass reflectors has been found to provide the most efficient type of projector, as it gives better results than aluminum or chromium-plated reflector units.

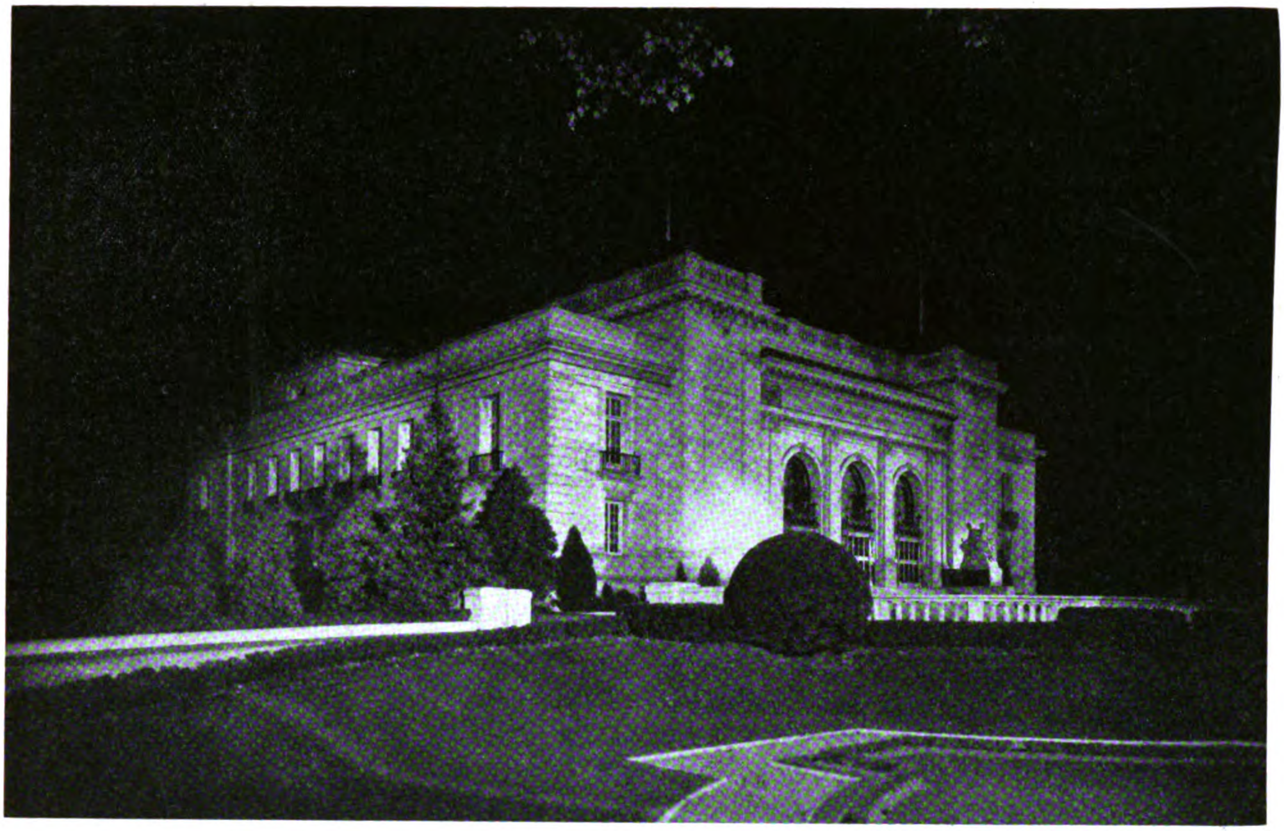
The accompanying arrangement of data (Chart 1) has been prepared to simplify calculations in solving floodlighting problems. It embodies the laboratory and field experience of illuminating engineers and takes into consideration the widest application of projectors and equipments of new, improved design.

A brief description will assist a clear understanding of the construction and application of this chart. It is designed as follows: The upper section shows sketches and general dimensions of the various types of floodlighting projectors. The second section indicates and briefly describes the type. The third section shows the number of projectors of each type required to illuminate various areas at different intensities. These data are in the form of curves and are based on clear-glass doors; similar data for other equipments are noted in the Table of Constants, which gives constants for different equipments, based on beam lumens, and also transmission factors for colored doors. Approximate working distances, based on 0.5 foot-candle are given graphically.

The lower section of the chart tabulates the efficiencies and general data for different equipments such as lamp wattage, type of bulb, and service, together with lamp lumens, total lumens, beam lumens, and beam width.

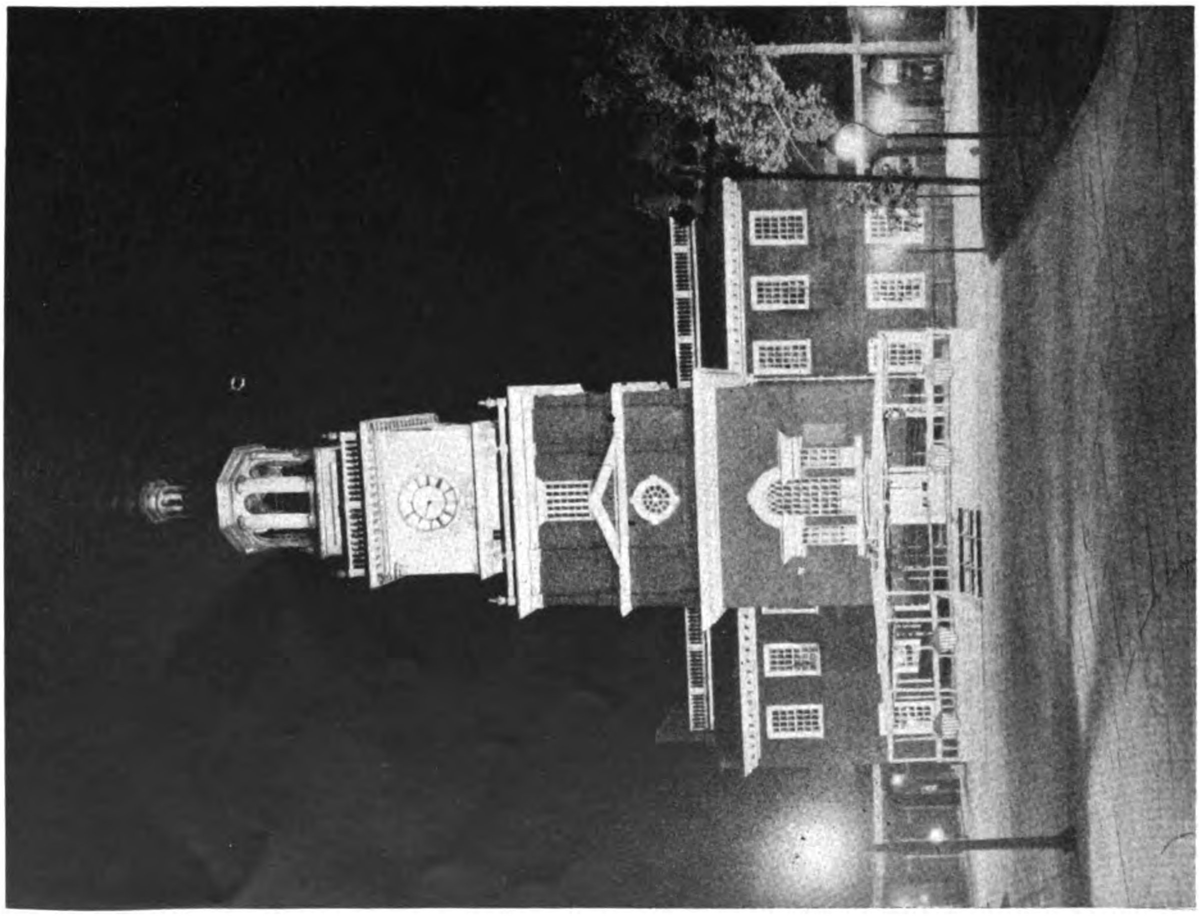
The diagram in the middle of the lower section of the chart shows beam diameters in feet for different distances. These data, it will be noted, are for surfaces normal to the beam. To obtain the average foot-candles on the surface normal to the beam, the following formula is applied:

$$\text{Ave. ft-cd.} = \frac{\text{Beam lumens}}{\text{Dia.}^2 \times 0.785}$$

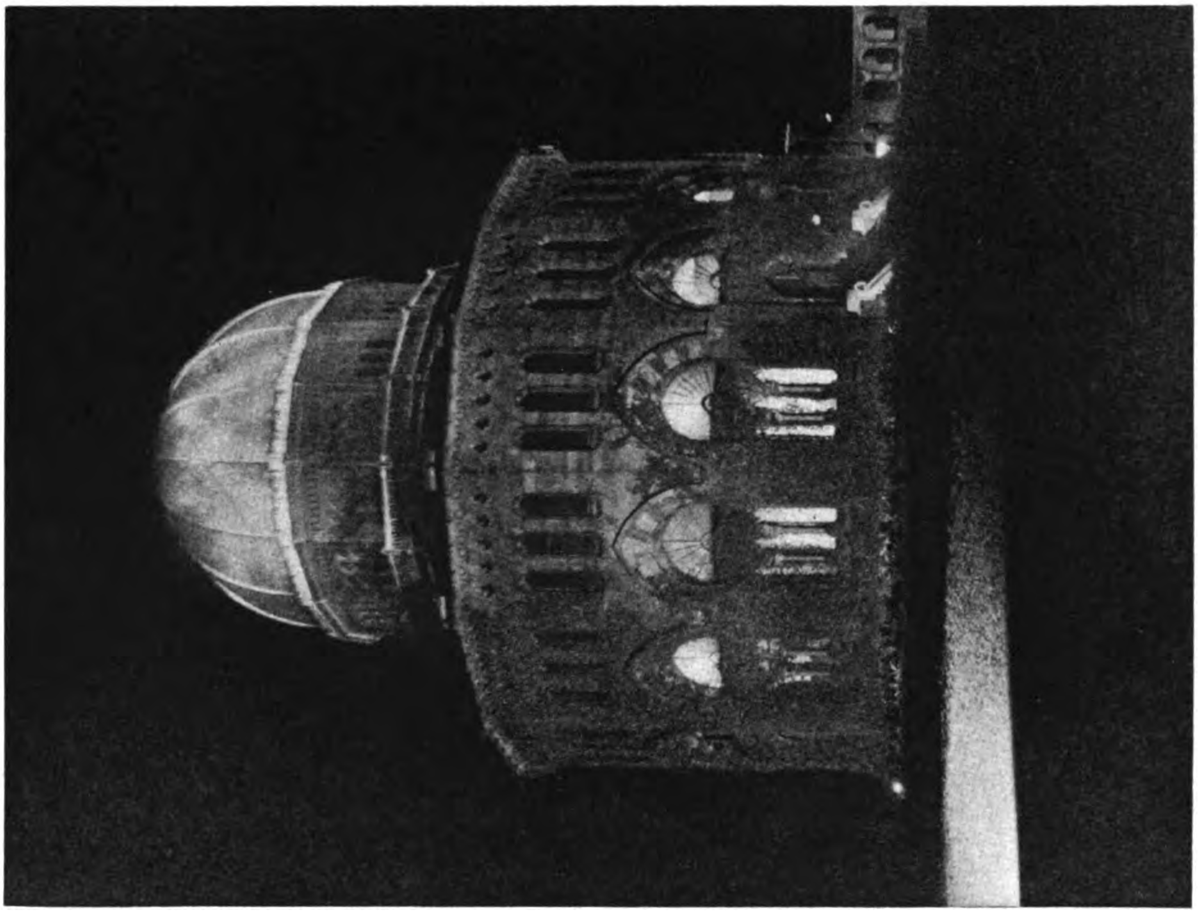


Pan-American Union, Washington (D. C.)

Administration Building, Staley Mfg. Co., Decatur (Ill.)



Independence Hall, Philadelphia (Pa.)



Union College Library, Schenectady (N. Y.)

In the lower right-hand section, tables of intensities suitable for various classes of floodlighting are shown.

In the extreme right-hand section of the chart are general data which will enable the engineers to determine the length and width of beams when the projectors are inclined at different angles. Instructions No. 1 and 2 outline the operation of these curves and are practically self-explanatory.

It will be found in practice that the floodlighting beam is generally inclined at various angles rather than on surfaces normal to the beam. The latter direction will form a symmetrical beam of but one dimension, the diameter; the former gives an elliptical beam of two dimensions, length and breadth. Information as to the elliptical beam is generally of the greater importance.

TABLE II

Number Clear Door	Type	Dividing Constants for Heav. Stip'd.	Number Projectors Heav. Stip'd	Watts	Total Kw. Load
24	L-30B (Narrow Beam)	1.07	23	500	11.5
12	L-31A	1.28	10	1000	10
11	L-31B	1.04	11	1000	11

Example 1: To exemplify the use of Chart 1, it will be helpful to work out a few practical problems. The first of these, let us say, requires computation of lighting for an area of 3000 sq. ft., surface approximately square. The conditions require that the unit be installed 400 ft. from the surface to be illuminated. The building is dark in color and is situated in a "whiteway" locality. What type of floodlighting unit should be used? What intensity is required, and what number of units? In solving this problem the controlling conditions are:

(1). The projectors are to be located 400 feet from the surface to be lluminated.

(2). The object to be illuminated is in a "whiteway" locality.

(3). The surface has a dark finish.

Reference to the tables of intensities for various classes of floodlighting, shows that under these conditions an illumination of 30 ft-cd. is necessary. By referring to the line "approximate working distances," in Chart 1, it is found that a number of projectors are suitable. These projectors are the L-30B with narrow beam reflector, L-31B, L-24A (1000-watt), L-24A (1500-watt), and L-24B with plain clear lenses. By referring to the curves given, the number of projectors to be used for various foot-candle intensities is found. A tabulation of units required is given in Table I.

TABLE I

Number	Type	Door	Beam	Watts	Total Kw. Load
24	L-30B	Clear	Narrow	500	12
11	L-31B	Clear	Narrow	1000	11
10	L-24A	Clear	Medium	1000	10
7	L-24A	Clear	Medium	1500	10.5
13	L-24B	Clear	Narrow	1000	13

It will be observed that in this case a smaller number of L-24A (1500-watt) projectors will be required. However, this should not be entirely the deciding factor, as the relative cost of the various systems may favor using a different type with a larger number of projectors with equal or less power but with more uniform distribution and less waste of light; *i.e.*, with a beam width that might be more suitable for floodlighting the area in question. To determine the latter factor, refer to the diagram in the lower middle section of Chart 1, which gives the beam diameter in feet for various beams and distances. This should enable one to determine which projector beam will cover the area with the least waste of light. This diagram may be applied in determining the most efficient or choice projector involved in the problem. Local conditions should also be a deciding factor.

Example 2: Assume 100 ft. working distance in the first problem instead of 400 ft. Since all curves in Chart 1 are calculated for clear glass doors, and since, at this distance, heavily stippled doors might be used in order to wash out the high spots and shadows, we must, in order to obtain the required 30 ft-cd., refer to the table of dividing constants (Chart 1).

The dividing constants for the various projectors that are suitable for the heavily stippled lens and for a working distance of 100 ft. or more (Example 2) are given in Table II.

From the tabulation, therefore, it appears that the L-31A projector is the most suitable for the second problem. However, a supplementary analysis should be made as outlined for Example 1; *i.e.*, whether the type that takes the least number of projectors covers the area in question with the least possible waste, investment cost, and power.

It will be observed that lightly stippled doors might be used with less waste, as the beam width is more suitable. (Note in this connection data for surfaces normal to beam; *i.e.*, beam diameter at various distances.) The heavily stippled door was proposed to eliminate glare and possibly obtain a more even distribution.

The table of constants for the various types of projectors with their respective glass-door equipment—clear, lightly stippled, heavily stippled, and wide-angle (Spredlite door)—should always be referred to because the plain clear-glass equipment is used as the basis, or 100 per cent.

Example 3: Assume that it is desired to know the beam diameter for surfaces normal to the beam and the average foot-candle illumination over the surface. Also assume that the L-30B projector is to be used with plain clear-glass door (44-deg. beam) and that the distance from the projector is 200 ft. By referring to the diagram in the lower middle section of the chart (which gives the beam diameter for various distances), the diameter for the Type L-30B projector with plain clear door, 44-deg. beam, is found to be approximately 160 ft. By applying the formula $\frac{\text{Beam lumens}}{\text{Dia.}^2\times 0.785}=$ ft-cd. on surface normal to the beam and by referring to the equipment efficiency table at the left-hand corner of the chart, we find that this type of projector gives 4250 beam lumens. Therefore

$$\frac{4250}{(160)^2\times 0.785}=0.21\text{ ft-cd.}$$

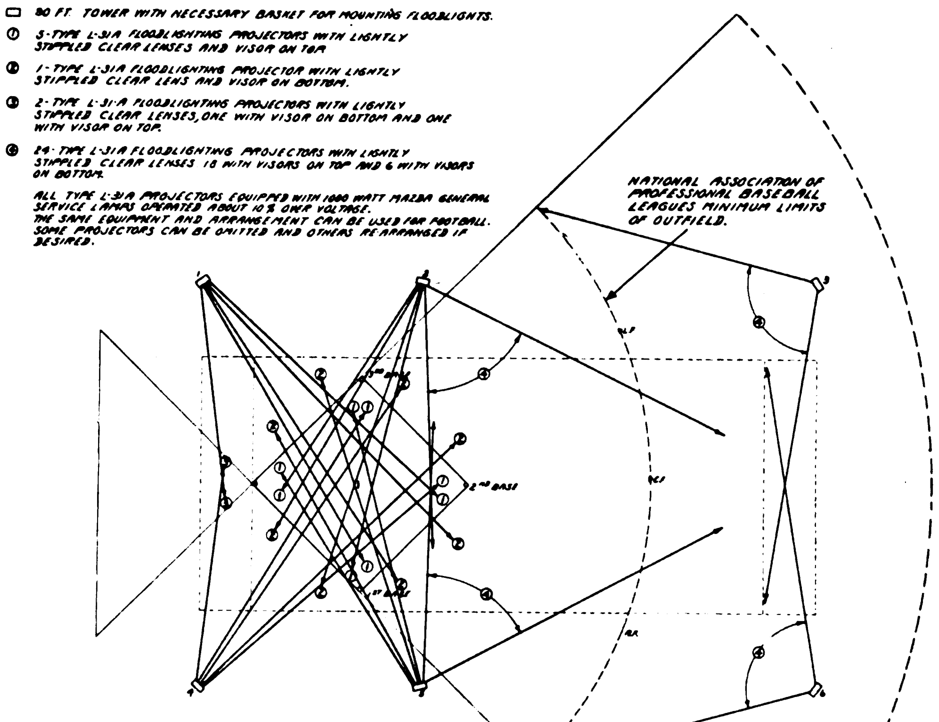
When computing intensity values, it is useful to note that full moonlight is approximately 1/40 ft-cd. (0.025 ft-cd.) and that with this intensity newspaper print can be read without difficulty.

Since the object to be floodlighted is generally above or below the level of the projector, it is usually found necessary to incline the beam rather than to direct it normally to the surface. In this case, an elliptical beam of two dimensions will be formed, as previously stated, the data for which can easily be obtained by referring to the diagram, or graphic section, at the right. Let us apply these diagrams in order to obtain the length and width of the beam as well as the formula for area and foot-candles in the beam.

Example 4: Assume that the Type L-29A projector with lightly stippled door is to be used; that the height H to the center of pattern or beam is 50 ft.; and that the distance to the lighted area is 64 ft. Referring to Instruction No. 1 in the floodlighting chart, we find that

$$\text{Ratio}=\frac{\text{Height}}{\text{Distance}}=\frac{50}{64}=0.78$$

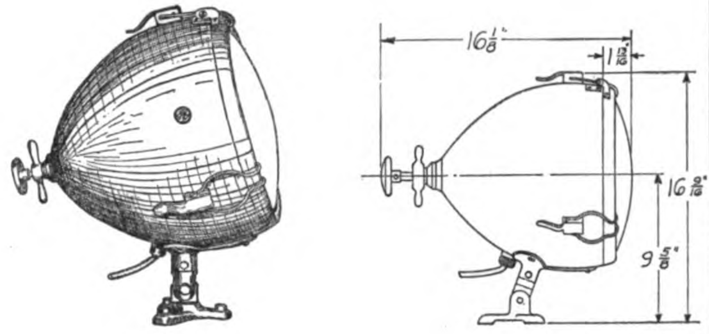
Referring to the ratio scale, we read the angle of inclination a = 38 deg. This is the first step. The second is to obtain the curve number and beam lumens of the projector by referring to the Table (Fig. 2). In this instance, the curve number is 6 and the value for beam lumens is 1400. Third step, refer to Instruction No. 2 (Figs. 3 and 4 on Chart 1), applying to a projector with lightly stippled door (Curve 6), thence to Fig. 3 on the chart and follow the vertical line of 38-deg. angle of inclination a to the intersections of Curve 6 and read on the left-hand scale the factor for width of beam,


▭ 80 FT. TOWER WITH NECESSARY BASKET FOR MOUNTING FLOODLIGHTS.
① 5-TYPE L-31A FLOODLIGHTING PROJECTORS WITH LIGHTLY STIPPLED CLEAR LENSES AND VISOR ON TOP
② 1-TYPE L-31A FLOODLIGHTING PROJECTOR WITH LIGHTLY STIPPLED CLEAR LENS AND VISOR ON BOTTOM.
③ 2-TYPE L-31-A FLOODLIGHTING PROJECTORS WITH LIGHTLY STIPPLED CLEAR LENSES, ONE WITH VISOR ON BOTTOM AND ONE WITH VISOR ON TOP.
④ 24-TYPE L-31A FLOODLIGHTING PROJECTORS WITH LIGHTLY STIPPLED CLEAR LENSES 18 WITH VISORS ON TOP AND 6 WITH VISORS ON BOTTOM.
ALL TYPE L-31A PROJECTORS EQUIPPED WITH 1000 WATT MAZDA GENERAL SERVICE LAMPS OPERATED ABOUT 10% OVER VOLTAGE.
THE SAME EQUIPMENT AND ARRANGEMENT CAN BE USED FOR FOOTBALL.
SOME PROJECTORS CAN BE OMITTED AND OTHERS RE-ARRANGED IF DESIRED.
NATIONAL ASSOCIATION OF PROFESSIONAL BASEBALL LEAGUES MINIMUM LIMITS OF OUTFIELD.
1
2
3
4
5
6
1ST BASE
2ND BASE
3RD BASE
0 30 60 FT
SCALE

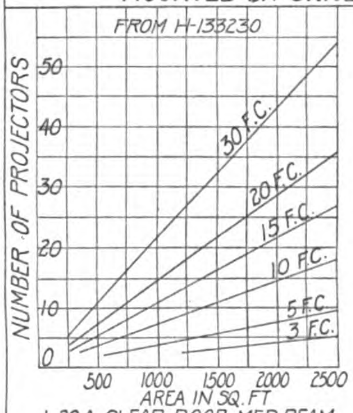
SUMMARY OF PROJECTORS

TOWER NUMBER	VISOR ON TOP	VISOR ON BOTTOM	TOTAL PROJECTORS
1	11	3	14
2	28	8	36
3	18	6	24
4	11	3	14
5	28	8	36
6	18	6	24
TOTAL	114	34	148

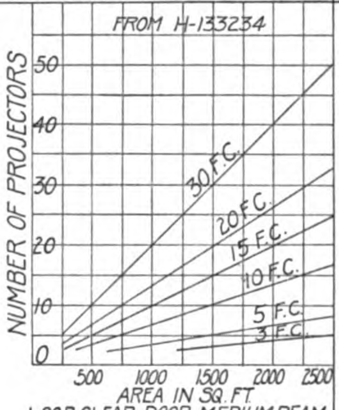
Chart 2: **Lighting Plan for a Baseball Field**



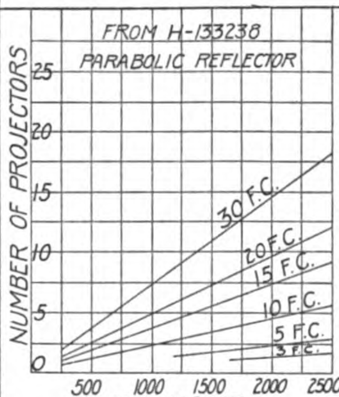
TYPE L-29 FLOODLIGHTING PROJECTORS
MOUNTED ON SWIVEL AND ROCKER BASE



L-29A, CLEAR DOOR, MED. BEAM



L-29B, CLEAR DOOR, MEDIUM BEAM



L-30A, CLEAR DOOR, MEDIUM BEAM

APPROX. MAX. WORKING DISTANCE BASED ON 0.5 AVE. F.C	L-29A	L-29B	L-30A
CLEAR DOOR	130 FT	190 FT	240 FT
LIGHTLY STIPPLED	90 "	110 "	170 "
HEAVILY STIPPLED	40 "	45 "	85 "
SPREDLITE DOOR	80 "	100 "	170 "

EQUIPMENT

CLEAR GLASS DOOR

TYPE	PHOTO CURVE	WATTS	BULB	SERVICE	REFLECTOR	LAMP LUMENS	TOTAL LUMENS	BEAM LUMENS	BEAM WIDTH
L-29A	H-133230	200	PS-30	GENERAL	GLASS	3300	2225	1393	26°V.X28°H.
L-29B	H-133234	250	G-30	FLOODLIGHTING		3500	2450	1500	18°V.X18.2°H.
L-30A	H-133238	500	PS-40	GENERAL		9500	6820	4164	20.6°VX26.6°H.
L-30A	H-133242	500	PS-40	GENERAL		9500	6940	4900	60°
L-30B	H-133149	500	G-40	FLOODLIGHTING		8300	5900	3796	11.2°VX13.3°H.
L-30B	H-133245	500	G-40	FLOODLIGHTING		8300	6080	4250	44°
L-31A	H-133248	1000	PS-52	GENERAL		20000	13650	7558	21°VX21°H.
L-31B	H-133201	1000	G-40	FLOODLIGHTING		17800	12620	8053	12.5°VX14.3°H.
L-24A	H-132934	1000	PS-52	GENERAL		21000	14720	8785	18°VX21.5°H.
L-24A	H-132995	1500	PS-52	GENERAL		30000	21440	12750	17.5°VX23°H.
L-24B	H-133101	1000	G-40	FLOODLIGHTING		17800	12440	6855	11.9°VX15.5°H.

LIGHTLY STIPPLED

TYPE	PHOTO CURVE	WATTS	BULB	SERVICE	REF
L-29A	H-133231	200	PS-30	GENERAL	
L-29B	H-133235	250	G-30	FLOODLIGHTING	
L-30A	H-133239	500	PS-40	GENERAL	
L-30A	H-133243	500	PS-40	GENERAL	
L-30B	H-133150	500	G-40	FLOODLIGHTING	
L-30B	H-133246	500	G-40		
L-31A	H-133249	1000	PS-52	GENERAL	
L-31B	H-133202	1000	G-40	FLOODLIGHTING	
L-24A	H-132993	1000	PS-52	GENERAL	
L-24A	H-132996	1500	PS-52		
L-24B	H-133104	1000	G-40	FLOODLIGHTING	

HEAVILY STIPPLED DOOR

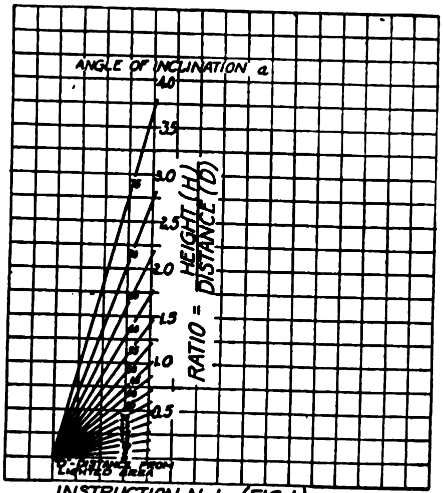
TYPE	PHOTO CURVE	WATTS	BULB	SERVICE	REFLECTOR	LAMP LUMENS	TOTAL LUMENS	BEAM LUMENS	BEAM WIDTH
L-29A	H-133232	200	PS-30	GENERAL	GLASS	3300	2205	1620	72°
L-29B	H-133236	250	G-30	FLOODLIGHTING		3500	2380	1660	68°
L-30A	H-133240	500	PS-40	GENERAL		9500	6470	4660	64°
L-30A	H-133244	500	PS-40			9500	6570	5800	98°
L-30B	H-133151	500	G-40	FLOODLIGHTING		8300	5725	4050	54°
L-30B	H-133247	500	G-40			8300	5820	4870	88°
L-31A	H-133250	1000	PS-52	GENERAL		20000	13420	9700	67°
L-31B	H-133203	1000	G-40	FLOODLIGHTING		17800	12300	8380	54°

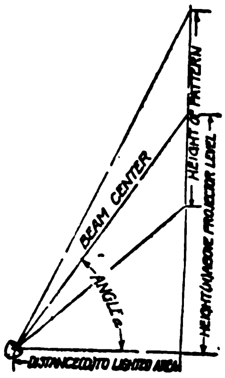
SPREDLITE DOOR

TYPE	PHOTO CURVE	WATTS	BULB	SERVICE	REFL
L-29A	H-133233	200	PS-30	GENERAL	
L-29B	H-133237	250	G-30	FLOODLIGHTING	
L-30A	H-133241	500	PS-40	GENERAL	
L-30B	H-133152	500	G-40	FLOODLIGHTING	
L-31A	H-133251	1000	PS-52	GENERAL	
L-31B	H-133204	1000	G-40	FLOODLIGHTING	
L-24A	H-132994	1000	PS-52	GENERAL	
L-24A	H-132997	1500	PS-52		
L-24B	H-133105	1000	G-40	FLOODLIGHTING	

CHART 1: FLOODLIGHTING DATA

Working distances indicated in this chart are based on areas of approximate average intensities of obtain closer relative beam spread of the projectors suitable to meet local conditions, refer to the graph section of chart showing beam diameter for various distances and for different beam spreads.




BEAM CENTER
ANGLE a
HEIGHT OF PATTERN
HEIGHT (H) ABOVE PROJECTOR LEVEL
DISTANCE (D) TO LIGHTED AREA

INSTRUCTION No. 1 - (FIG. 1)

$$\frac{\text{HEIGHT (H)}}{\text{DISTANCE (D)}} = \text{RATIO}$$

READ ANGLE OF INCLINATION (a) FROM RATIO SCALE FIGURE 1 - EXAMPLE HEIGHT 50 FT. DISTANCE 64 FT., RATIO IS THEN .78 AND ANGLE OF INCLINATION (a) 38°.

CURVE NO.	TYPE	LENS	WATTS	LAMP	BEAM LUMENS	
3	L-29-A	PLAIN (CLEAR)	200	PS-30	1393	
6	L-29-A	LIGHTLY STIPPLED	200	PS-30	1400	
10	L-29-A	HEAVILY STIPPLED	200	PS-30	1620	
2	L-29B	PLAIN (CLEAR)	250	PS-30	1500	
3	L-30-A	PLAIN (CLEAR)	500	PS-40	4164	
4	L-30A	LIGHTLY STIPPLED	500	PS-40	4157	
9	L-30A	HEAVILY STIPPLED	500	PS-40	4660	
8	L-30-A	PLAIN (CLEAR)	500	PS-40	4900	SECTIONAL REFLECTOR
10	L-30-A	LIGHTLY STIPPLED	500	PS-40	5375	
11	L-30-A	HEAVILY STIPPLED	500	PS-40	5800	
1	L-30-B	PLAIN (CLEAR)	500	G-40	3796	
7	L-30-B	HEAVILY STIPPLED	500	G-40	4050	
5	L-31-A	LIGHTLY STIPPLED	1000	PS-52	7900	
9	L-31-A	HEAVILY STIPPLED	1000	PS-52	9700	
1	L-31-B	PLAIN (CLEAR)	1000	G-40	8053	
3	L-31-B	LIGHTLY STIPPLED	1000	G-40	7667	
2	L-24-A	PLAIN (CLEAR)	1500	PS-52	12750	
3	L-24-A	LIGHTLY STIPPLED	1500	PS-52	12560	

TABLE (FIG. 2)

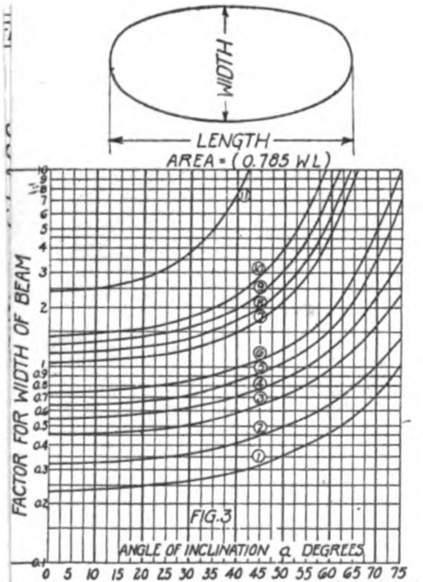


FIG. 3

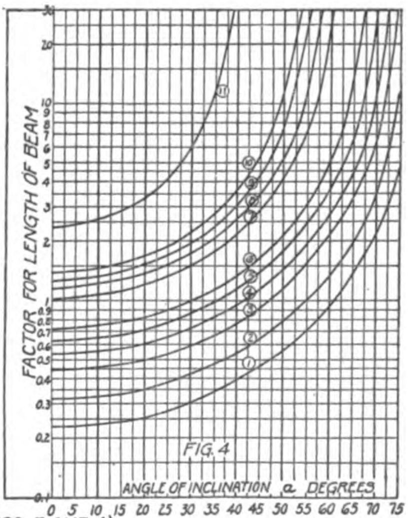


FIG. 4

INSTRUCTION No. 2 - (FIGS. 3 AND 4)

SSUME L-29A LIGHTLY STIPPLED DOOR. CURVE #6, TABLE FIG. #2. IN FIG. #3 FOLLOW VERTICAL LINE OF 38° ANGLE (a) TO TERSECTIONS OF CURVE 6 AND READ ON LEFT HAND SCALE FACTOR .97 AND MULTIPLY BY DISTANCE D-64 FEET ING WIDTH OF BEAM (W) — 62 FEET TO OBTAIN LENGTH OF BEAM "L" FOLLOW SIMILAR PROCEDURE AS IN FIG. #3.

$$\text{F.C.} = \frac{\text{BEAM LUMENS}}{\text{AREA}}$$

(0.97) and multiply by the distance 64 ft. which gives the width of the beam W as 62 ft. To obtain the length of the beam L, proceed in Fig. 4 as in Fig. 3, *i.e.*, follow the vertical line of 38-deg. angle of inclination a to the intersection of Curve 6 and read on left-hand scale the factor for length of beam (approximately 1.3) and multiply by the distance D, 64 ft., which gives the length of beam L as 83 ft.

The fourth step is to obtain the foot-candles in the beam by applying the formula

$$\text{Ft-cd.} = \frac{\text{Beam lumens}}{\text{Area}}$$

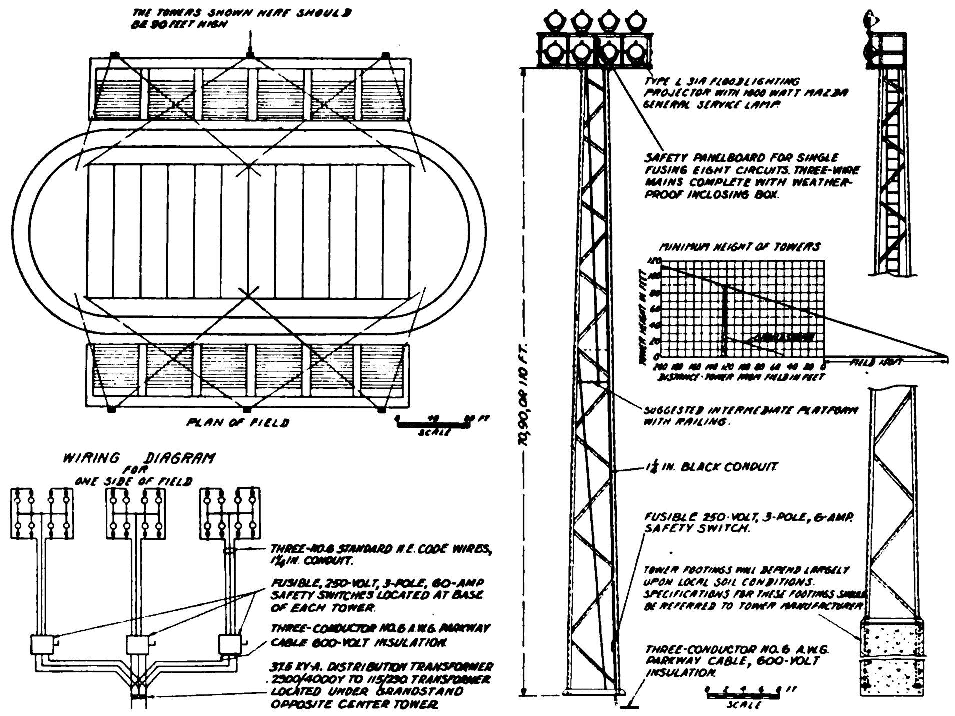

THE TOWERS SHOWN HERE SHOULD BE 90 FEET HIGH
PLAN OF FIELD
0 40 80 FT
SCALE
WIRING DIAGRAM FOR ONE SIDE OF FIELD
THREE-NO. 6 STANDARD N.E. CODE WIRES, 1¼ IN. CONDUIT.
FUSIBLE, 250-VOLT, 3-POLE, 60-AMP SAFETY SWITCHES LOCATED AT BASE OF EACH TOWER.
THREE-CONDUCTOR NO. 6 A.W.G. PARKWAY CABLE 600-VOLT INSULATION.
37.5 KV-A. DISTRIBUTION TRANSFORMER 2300/4000Y TO 115/230 TRANSFORMER LOCATED UNDER GRANDSTAND OPPOSITE CENTER TOWER.
70, 90, OR 110 FT.
TYPE L 31A FLOODLIGHTING PROJECTOR WITH 1000 WATT MAZDA GENERAL SERVICE LAMP.
SAFETY PANELBOARD FOR SINGLE FUSING EIGHT CIRCUITS. THREE-WIRE MAINS COMPLETE WITH WEATHERPROOF INCLOSING BOX.
MINIMUM HEIGHT OF TOWERS
TOWER HEIGHT IN FEET
120 100 80 60 40 20 0
200 180 160 140 120 100 80 60 40 20 0
DISTANCE - TOWER FROM FIELD IN FEET
FIELD LIGHT
SUGGESTED INTERMEDIATE PLATFORM WITH RAILING.
1½ IN. BLACK CONDUIT.
FUSIBLE 250-VOLT, 3-POLE, 6-AMP. SAFETY SWITCH.
TOWER FOOTINGS WILL DEPEND LARGELY UPON LOCAL SOIL CONDITIONS. SPECIFICATIONS FOR THESE FOOTINGS SHOULD BE REFERRED TO TOWER MANUFACTURER.
THREE-CONDUCTOR NO. 6 A.W.G. PARKWAY CABLE, 600-VOLT INSULATION.
0 2 4 6 8 "
SCALE

Chart 3: **Lighting Layout for a Football Field**

Summary of Materials:

48 Type L-31A Novalux floodlighting projectors with lightly stippled clear lenses
48 1000-watt Mazda clear lamps, 105-volt (10 per cent less than circuit voltage)

Note: Where it is necessary to locate towers over 100 ft. from the edge of the field use 48 projectors of Type 31 A, as before, but equipped with plain clear lenses.

450 ft. (approx.) 1¼-in. black conduit
50 ft. (approx.) 1½-in. black conduit
12 1½-in. black standard 90 deg.-elbows
6 Safety panel boards for eight circuits, three-wire mains complete with weatherproof enclosing box
2150 ft. (approx.) No. 6 A. W. G. standard N. E. Code wire
800 ft. (approx.) three-conductor No. 6 A. W. G. Parkway cable, 600-volt insulation
6 fusible 250-volt three-pole 60-amp. safety switches
2 37.5-kv-a. 2300/4000 to 115/230 distribution transformers
6 towers with necessary baskets
Necessary small conduit fittings

The area of an elliptical beam is $0.785 \times W \times L$; therefore the complete foot-candle formula for an elliptical beam is

$$\text{Ft-cd.} = \frac{\text{Beam lumens}}{0.785 \times W \times L}$$

In this problem, we obtain

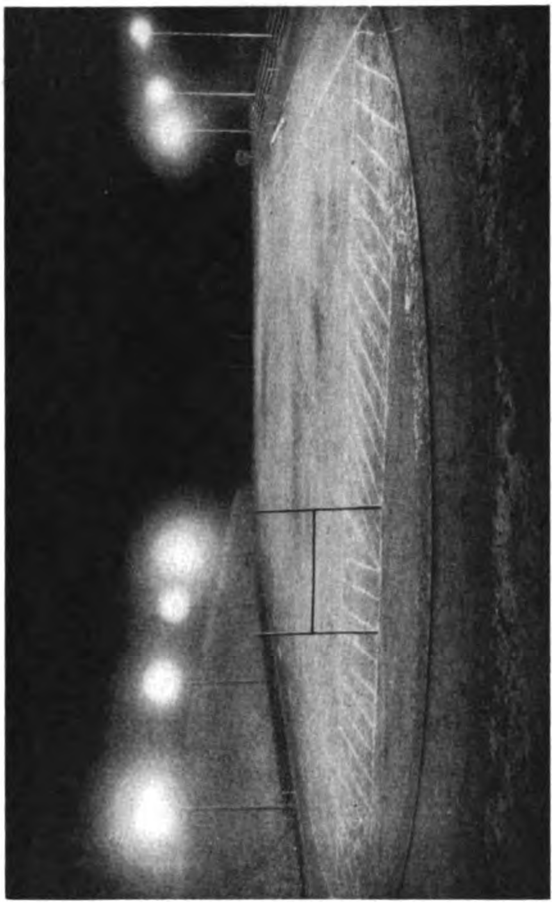
$$\text{Ft-cd.} = \frac{1400}{0.785 \times 62 \times 83} = 0.36 \text{ ft-cd.}$$

Other problems are solved in a similar manner.

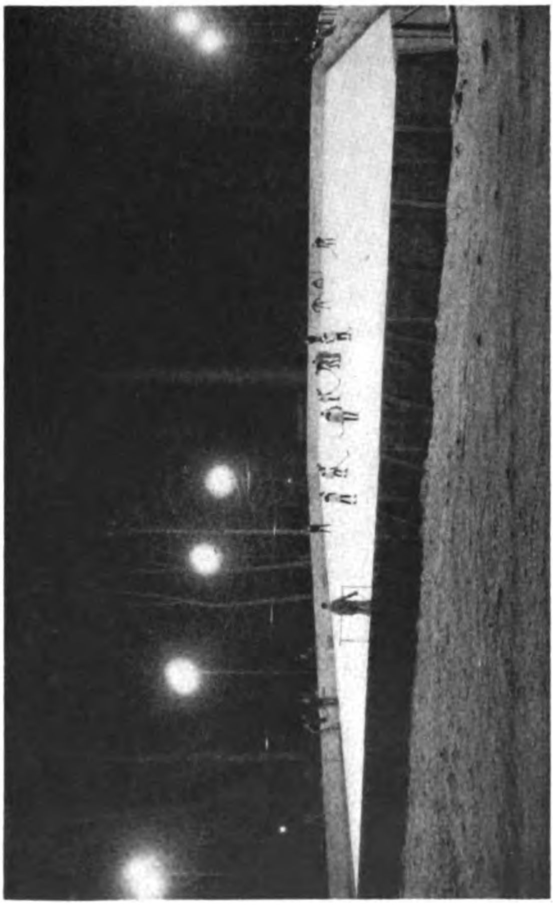
Brief reference has already been made to the floodlighting of baseball and football fields and running tracks. The success of the many installations now in operation have definitely removed the experimental stage and have established this innovation as a profitable investment. Thoroughly effective illumination is obtained by the use of projectors of the correct intensities and grouping, scientifically designed, properly focused and spaced to meet the individual requirements of the field. Such an installation gives bright, shadowless, glareless, uniform visibility. Charts 2 and 3 show diagrams and specifications for the floodlighting of athletic fields.

Chart 2 outlines requirements for the illumination of a baseball field with enclosed floodlights (Class A). The general data gives the respective types and number of projectors for each tower. The Class B installation, combining enclosed and open-type reflectors, represents a low initial investment, and hence may probably be the most popular practice until the advantages of the completely enclosed projector type of installation are more generally appreciated.

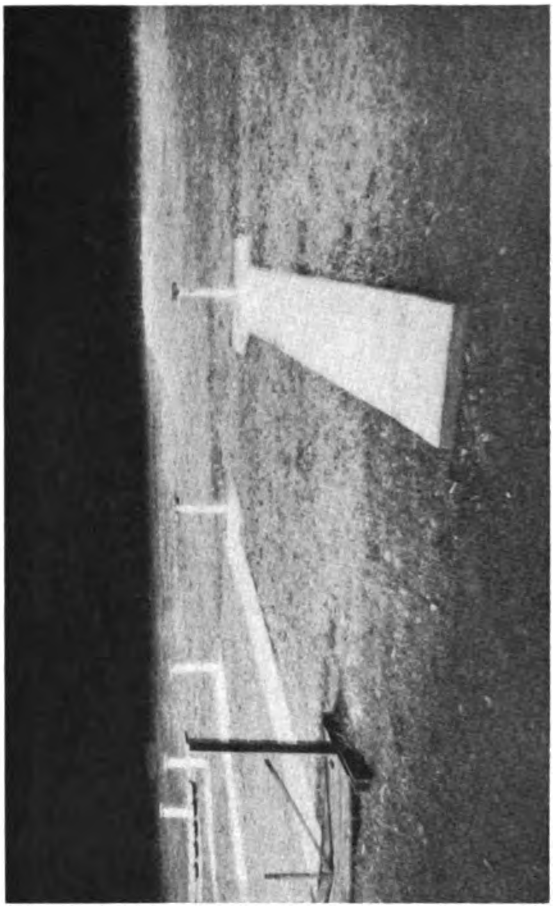
In the open-type projector, the accumulation of dirt on the reflector reduces the coefficient of reflection; furthermore, this type is not adaptable to the various glass lenses, or doors, that give so flexible a range of distribution. On the other hand, the enclosed type is protected from dirt; this helps to maintain



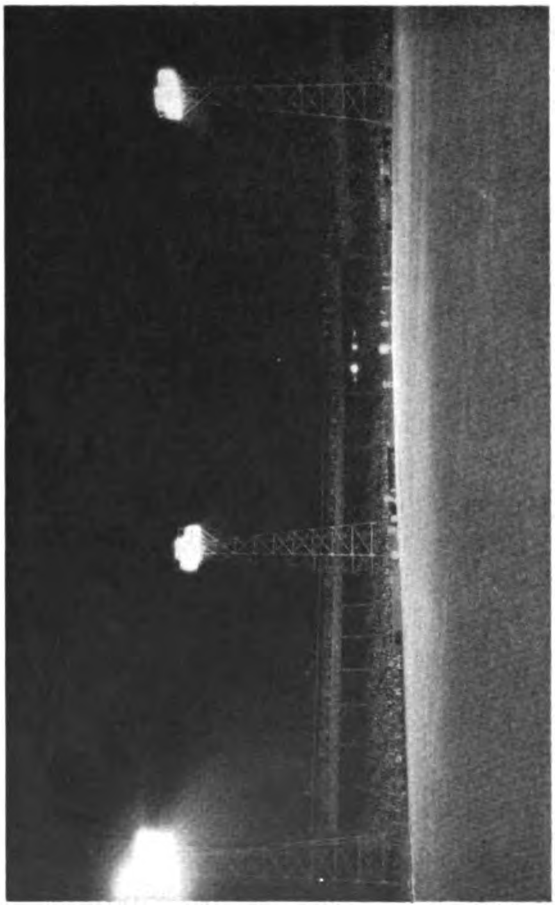
High School Stadium, Schenectady (N. Y.)



Union College Hockey Court, Schenectady (N. Y.)



Altamont Gun Club, Altamont (N. Y.)



Washington Baseball Park, Indianapolis (Ind.)

the coefficient of reflection. Also, the enclosed type can be controlled more efficiently, and its use is rendered highly flexible by means of the various lenses that can be applied to different types of distribution. There is, too, a tendency to reduction of glare—a very important factor in many fields of floodlighting application.

Chart 3 shows lighting plans for enclosed-reflector installations at football fields. The floodlighting towers are behind the bleachers. In most instances, it is desirable to locate the projectors behind the stands or bleachers. The field is illuminated to an average intensity of approximately 9.0 ft-cd. with the lamp operated at 10 per cent overvoltage. The operation of lamps at this rating for football and baseball illumination represents a very practical and most economical balance between lamp life and lumen output, *i.e.*, approximately 38 per cent increase in light and 70 per cent decrease in lamp life.

Steam Plant, New York Power & Light Corp., Amsterdam (N. Y.)

The procedure for initial adjustment is as follows:

(1). Adjust each tower with all others turned off.

(2). Focus projectors for minimum divergence with doors open.

(3). Close doors and adjust beams to light near side of field with upper edge of beam at far edge of field.

Complete Class A information is contained in charts.

The experience gained in recent installations at athletic fields (a partial list of which appears at the end of this article) indicates that the following factors are important and, in most cases, represent actual requirements.

(1). Better visibility, less glare, and more uniform distribution of light are obtained where the equipment is mounted behind the stands or bleachers.

(2). To produce illumination free from objectionable glare, the lighting equipment should not, in any event, be mounted less than 55 ft. above the playing field. This height is permissible only where the projectors are mounted on poles or towers 12 to 15 ft. away from the field. Where the bleachers or stands make it advisable to erect the towers at some distance from the field, it is essential that the height of the towers be so increased that the projected light angle with the far side of the field shall be not less than 18 deg.

(3). It has been found that the foot-candles on the field are not of first importance. Distribution (evenness of illumination), correct angles of projection, and sufficient upward light are of greater importance. Intensities ranging from 4.5 to 9 ft-cd. are considered adequate in most cases. Upward light, although difficult to measure, plays an important part in football and baseball illumination. It is obvious, therefore, that a balance between upward light and horizontal intensity, combined with the desirable features already mentioned, should form the basis for this class of lighting.

(4). Experience has shown that 34 kw. arranged in proper projection equipment, and mounted from 50 to 60 ft. high and not more than 20 ft. from the field, will provide adequate illumination for games. This is the minimum lighting load required to play a football game at night. It has also been determined that a connected lighting load of 48 kw. is the practical minimum for the larger and better class of high-school athletic fields. (1)

(5). Control of projected light, essential in football illumination, can best be obtained by projectors which have a well-designed optical system and are so mounted that they can be adjusted readily. Totally enclosed projectors provided with silvered-glass reflectors have proved to be the most economical over an extended period.

---

(1) For more important athletic fields, approximately 200-kw. connected load is found practical for baseball fields, and an average of approximately 70 kw. for football fields.

Pennsylvania Power & Light Co. Building, Allentown (Pa.)

(6). The few burning-hours required of football installations make it possible to operate the lamps at approximately 10 per cent overvoltage, with the result that the over-all cost of a unit of light is reduced. Ten per cent increase in voltage represents approximately 38 per cent increase in light, with a 70 per cent decrease in the life of the lamp. On this basis, a lamp will operate approximately three seasons at the average field.

PARTIAL LIST OF ATHLETIC FIELDS LIGHTED WITH GENERAL ELECTRIC EQUIPMENT

Name	City	Approx. Kw. Load
Legion Field	Birmingham, Ala.	82.5
Grant Football Field, Georgia Institute of Technology	Atlanta, Ga.	72
Philadelphia Municipal Stadium	Philadelphia, Pa.	288
Tacoma Stadium	Tacoma, Wash.	60
Des Moines Western League Baseball Ground	Des Moines, Iowa	176
Fresno State College Football Field	Fresno, Calif.	60
Indianapolis (Baseball) American Association	Indianapolis, Ind.	200
Shreveport (Baseball)	Shreveport, La.	172
Oklahoma City (Baseball)	Oklahoma City, Okla.	180
Bridgeport Baseball Association	Bridgeport, Conn.	196
Moline Baseball Association	Moline, Ill.	207
Rock Island Baseball Association	Rock Island, Ill.	196
Baltimore Baseball Association	Baltimore, Md.	196
St. Louis Stars Baseball Association	St. Louis, Mo.	196
Albany Baseball Association	Albany, N. Y.	202
Reading Baseball Association	Reading, Pa.	196
Eureka High School Football Field	Eureka, Calif.	72
College of the Pacific Football Field	Stockton, Calif.	66
College of Idaho Football Field	Caldwell, Idaho	44
Oskaloosa High School Football Field	Oskaloosa, Iowa	75
Nebraska State Normal College Football Field	Carden, Nebr.	40
Nebraska Wesleyan College Football Field	Lincoln, Nebr.	40
School Stadium	Newark, N. J.	56
Knox Athletic Field	Johnstown, N. Y.	70
N. C. State College Football Field	Raleigh, N. C.	34
N. D. Agricultural College Football Field	Fargo, N. D.	36
Temple University Football Field	Philadelphia, Pa.	72
Kansas Wesleyan College Football Field	Salina, Kansas	40

Boston & Maine R.R. Yard, Mechanicville (N. Y.)

A Fourteen-story Office Building Field Arc-welded in Boston, Mass.

Design—Erection and Field Welding—Qualification of Welders—Inspection—Data

By FRANK P. McKIBBEN
Consulting Engineer (Black Gap, Pa.), General Electric Company

WHEN one sees the two-thousand-year-old Roman bath tub exhibited in the Field Museum in Chicago, made of pieces of bronze welded (brazed) together, with handles attached to the body of the tub by bronze rivets, he recalls the old and familiar quotation from Ecclesiates 1:9, that "There is no new thing under the sun." But when he stands on historic Boston Common to view the Edison Electric Illuminating Company's fourteen-story office building being arc-welded on Tremont Street opposite the Common, he is inclined to think that the old adage is wrong, or possibly that welding a structure so large is merely an "exception that proves the rule."

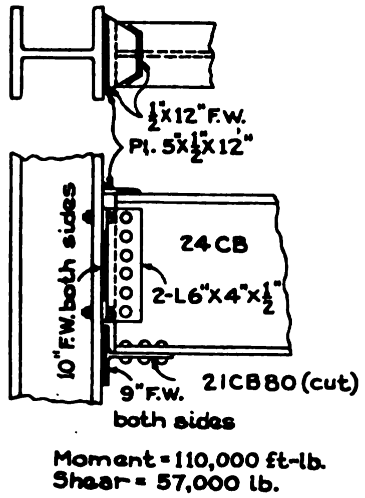


Fig. 1. Typical Connection of 24-in. Girder to Column Flange; Moment 110,000 ft-lb. Shear 57,000 lb.

NOTE: In Figs. 1, 2, 3, 4, 6, 7, and 8 all rivets and bolts are of ⅞-in. dia.; and the welds are ⅜-in. fillet welds unless otherwise noted.

The arc-welding process is developing so rapidly that no sooner do we decide that a fourteen-story welded structure is "the latest thing," when the beginning of an all-welded nineteen-story office building in Dallas requires us to establish a new standard. Seemingly the end is not yet.

The Edison Building is nearly rectangular in plan; 58 ft. on Tremont Street, 110 ft. at right angles thereto, and 187 ft. high from the sidewalk grade to the top of the sign platform on the elevator pent house. Because the structure is surrounded by hotels and office buildings, field welding was decided upon to reduce the noises of construction, but as this is the first building in Boston to be welded and in order to secure as many bidders on the steel as possible, standard riveted shop connections were used. This made it possible for the Edison Company to receive the benefit of competition by permitting existing steel fabricating companies to utilize their customary shop practices, while at the same time securing the advantages of reduction in noise by adopting arc-welding for field connections.

The steel frame is therefore shop riveted and field welded.

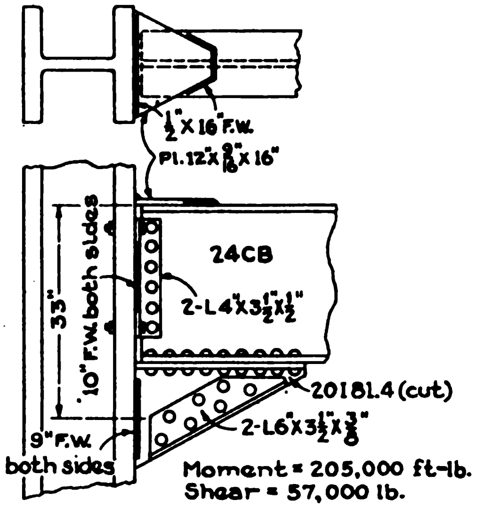


Fig. 2. Typical Connection of 24-in. Girder to Column Flange; Moment 205,000 ft-lb. Shear 57,000 lb.

Design

Due to certain provisions in the leases of the land on which the building stands, requiring the structure to be designed for "any commercial use allowed by the zoning law," an unusually heavy live load of 125 lb. per sq. ft. of floor area was used in designing the floor systems. And because of the relatively narrow width of 58 ft. as compared with the height of 187 ft., provisions to resist rather high wind stresses were necessary in proportioning the steel members and their connections. Figs. 1, 2, 3, and 4 illustrate four types of wind connection for varying amounts of wind moments.

Fig. 1, depicting a typical connection of a 24-in. girder beam to the flange of a column where a moment of 110,000 ft-lb. is to be transmitted, shows a "wind connection" consisting of a girder beam cut to form a T which is shop riveted to the lower flange of the 24-in. beam and its flange field welded to the face of the column. At the top flange of the 24-in. beam, the stress is transferred from the beam to the column by a 5-in. by ½-in. by 12-in. plate field welded both to beam and column. The end shear of 57,000 lb. is carried into the end connecting angles by six shop rivets, thence into the column by 20 in. of ⅜-in. field welding. The customary way of designating field welding by the letters *FW* is indicated in Fig. 1.

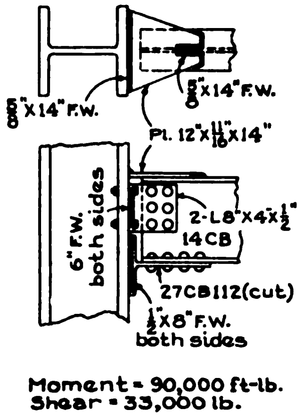

⅝"X14" F.W.
⅝"X14" F.W.
Pl. 12"X$\frac{11}{16}$"X14"
6" F.W. both sides
2-L8"X4"X½"
14CB
27CB112(cut)
½"X8" F.W. both sides
Moment = 90,000 ft-lb.
Shear = 33,000 lb.

Fig. 3. Typical Connection of 14-in. Beam to Column Flange; Moment 90,000 ft-lb. Shear 33,000 lb.

In those cases where the end bending moment on the girder is larger than can be provided for by the design in Fig. 1, the split girder beam is arranged as in Fig. 2. It acts as a gusset to increase the effective depth; the flange of the split beam being shop riveted to the lower flange of the girder, and the left edge of the web field welded with 18 in. of fillet to the face of the column. The connection in Fig. 2 is one in which the sloping edge of the gusset is stiffened by two 6-in. by 3½-in. by ⅜-in. angles.

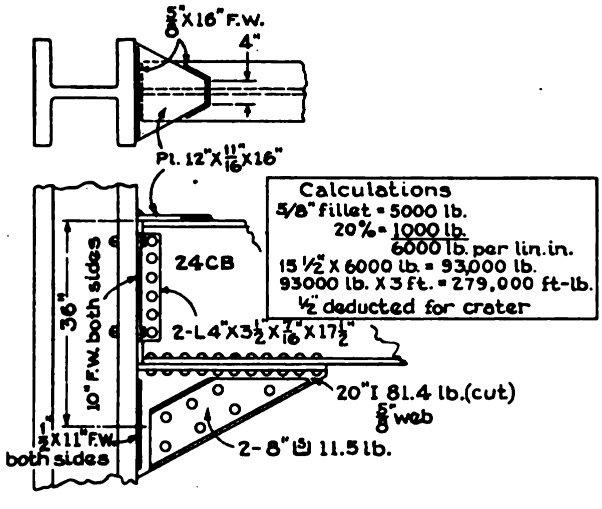

⅝"X16" F.W.
4"
Pl. 12"X$\frac{11}{16}$"X16"
Calculations
5/8" fillet = 5000 lb.
20% = 1000 lb.
6000 lb. per lin. in.
15 ½" X 6000 lb. = 93,000 lb.
93000 lb. X 3 ft. = 279,000 ft-lb.
½" deducted for crater
24CB
36"
10" F.W. both sides
2-L4"X3½"X$\frac{7}{16}$"X17½"
20"I 81.4 lb.(cut)
⅝" web
½"X11" F.W. both sides
2-8" ⊔ 11.5 lb.

Fig. 4. Typical Connection of 24-in. Girder to Column Flange; Moment 279,000 ft-lb. See also Fig. 11

Another interesting connection of a 24-in. girder to the flange of a column is shown in Fig. 4 where the web of the split 20-in. I-beam is reinforced by two 8-in. channels. Consider the moment carried by the welds at top of the 24-in. girder and those near the bottom of the bracket. At the top are 16 in. of ⅝-in. fillet, which for the live and dead stresses are good for 5000 lb. per linear inch of fillet at 11,300 lb. per sq. in. of minimum section. But for combined wind, live, and dead load, 20 per cent additional is used, making 6000 lb. per linear inch. From the 16 in. of fillet, ½ in. is deducted for crater, leaving 15½ in. effective welding. This at 6000 lb. provides a strength of 93,000 lb. Multiplying this by the lever arm of 3 ft., the available moment is 279,000 ft-lb., without allowing anything for the erection bolts or the 20 in. of fillet on the end connecting angles.

With wind-gusset plates used in this kind of welded connection, it is important to have the vertical edge of the split girder web in line with the back of the connecting angles in order to secure a proper joint for field welding.

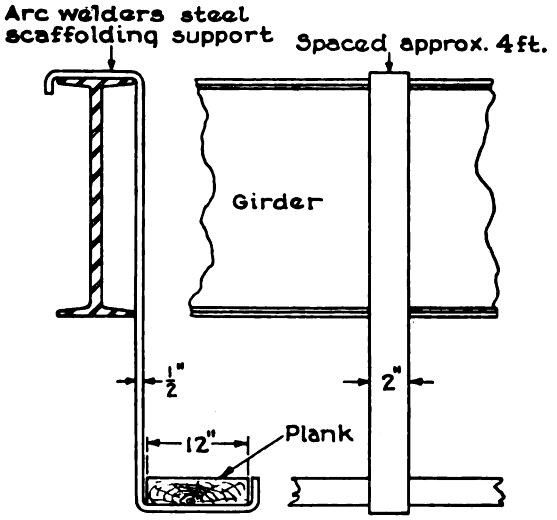

Arc welders steel scaffolding support
Spaced approx. 4 ft.
Girder
½"
2"
12"
Plank

Fig. 5. Steel Yoke for Supporting Plank to Serve as Welder's Platform

Sufficient field bolts were provided to insure proper plumbing and bracing in erection, and to draw the steel closely together preparatory to welding. The steel frame, both before and after welding, was unusually rigid.

The specifications for welding included the following subjects: definitions, quality of materials, apparatus, permissible unit stresses, workmanship, qualification of welders, proportion of parts, and protection of steel.

Boston Building Code

The building code of Boston, prescribed by a Massachusetts statute of rather long standing, makes no provision for welding; but being a code of the "flexible" type, the Building Commissioner granted a permit to field weld the structure under that section of the code which gives him discretionary powers to use a new material upon receipt of evidence that it is satisfactory for the purposes intended. The particular section embodying this power is as follows:

"*Systems Not Covered by This Act.*—If an applicant for a permit to build desires to use as a substitute for the materials or methods covered by this act, materials or methods of construction or maintenance not covered by it, he shall present to the commissioner plans, formulas, and such other information, and shall make such tests or present satisfactory evidence of such tests, as the commissioner may require. Such systems shall not be used until after the commissioner has issued general regulations fixing the methods to be followed, but no such regulation shall have the effect of altering the working stresses for any material herein mentioned or of reducing the fire-proofing requirements of this act."

The New England Building Officials Conference is now engaged in preparing a uniform building code, and no doubt provisions for welding will be incorporated therein. At all events, if this organization is successful in formulating such a desideratum as is a uniform code, and it is adopted by cities throughout New England, a great forward step will have been taken, and will be hailed with satisfaction by numerous engineers, architects, and builders.

Erection and Field Welding

All field connections at column splices, at connection of beams to beams, and of beams to girders, and at connection of beams and girders to columns are arc-welded. Many cities permit connections of secondary floor beams to be permanently field bolted, but as the normal Boston practice is to rivet these connections, they were field welded in this structure, a few bolts being used in each place only for erection purposes.

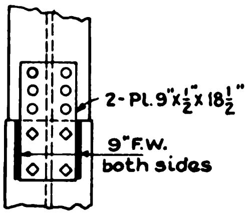


Fig. 6. Typical Column Splice with Both Splice Plates Narrower Than the Column Flanges for Use Where No Interference with Welding Exists

In general it was not necessary to erect platforms or other supports for the welders while at work on the various joints, but in those cases where platforms were needed they consisted of a short plank supported in steel yokes made by hooking a light Z-shaped steel frame over the top flange and alongside of the floor beam, Fig. 5. The cost of staging required for welders is small in general, and certainly in this Boston building the cost was very slight.

The statement is sometimes made that welding is so slow as to retard erection. The writer has not found this to be the case, as indicated by the following dates for this structure:

Steel erection was begun April 9, 1930, with setting of foundation grillages and cantilevers.
Welding was begun April 28, 1930.
Erection completed June 26, 1930.
Welding completed June 27, 1930.

Four welding machines were used, each a single-operator motor-generator set; all were set on the first floor where they remained throughout the work except during a brief period when moved to permit the reinforced concrete floor slab to be cast at their original location. In general it is preferable not to set the welding machines in the building, because they may interfere with building operations as in this case where they had to be moved during concreting. There was no other space available near the Edison Building, however. A meter was provided for each machine for recording the electrical energy supplied. As the building is not over 187 ft. high, only a slight drop in voltage was noticed, resulting from the increased length of leads necessary as the welders worked on the upper stories. In general it may be said that the amperage was approximately 175 at the lower and 185 at the upper floors. Three welders were employed until May 13th when a fourth was added. These four welders, one welding foreman, and one "engineer" constituted the entire welding force. For four welding machines, only four welders and one welding foreman are needed.

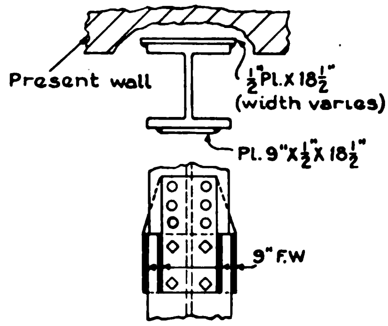
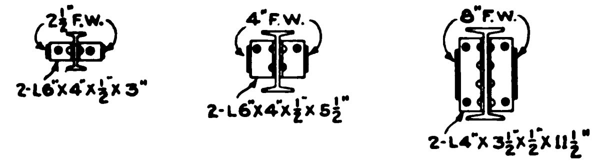


Fig. 7. Typical Column Splice with Front Splice Plate Narrower and Rear Splice Plate Wider Than Column Flange to Allow For Welding From One Side Only



For 6"-7" Is & ⊏s For 8"-9"-10"-12" Is & ⊏s For 15" & 18" Is

Fig. 8. Typical Connections for Beams to Beams

Typical column splices are shown in Figs. 6 and 7, the former indicating the usual design for the splice where the column is in such a position that all sides are accessible for welding, while Fig. 7 illustrates a case where welding can be performed from one side only because of the column being located against the wall of an adjacent building. By the simple device of using a narrow splice plate on the front and a wider one on the rear flange, the welding was done from the front without interference from the wall, and no cutting into the wall was necessary so far as welding was concerned.

Typical connections of beams to beams are shown in Fig. 8. Thus, for the 15-in. and 18-in. I-beams, two 4-in. by 3½-in. by ½-in. angles with a total of 16 linear inches of ⅜-in. fillet are used to carry the end shear. As the permissible unit stress is 3000 lb. per linear inch for live and dead loads, this end welding is capable of carrying 3000 times 16 or 48,000 lb. in direct shear. The connecting angles provide flexibility.

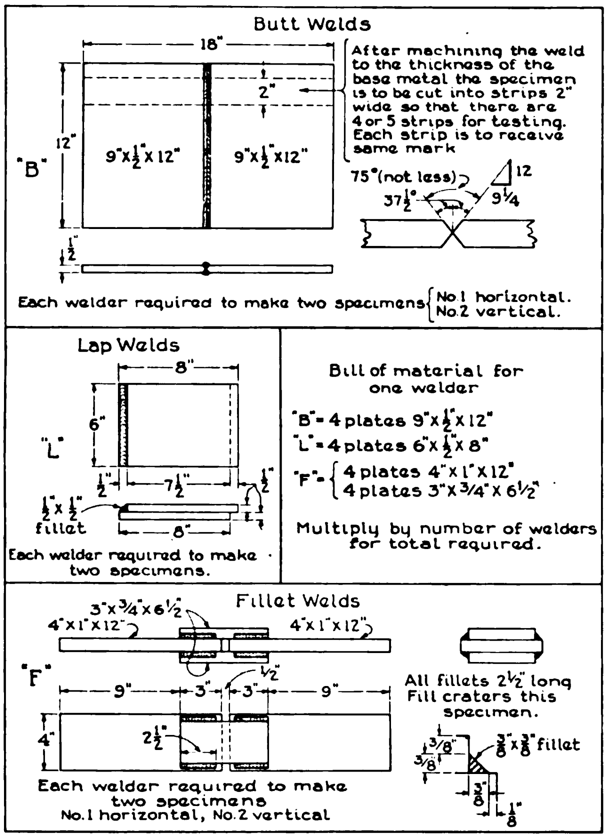

Butt Welds
18"
2"
12"
"B"
9"x½"x12"
9"x½"x12"
After machining the weld to the thickness of the base metal the specimen is to be cut into strips 2" wide so that there are 4 or 5 strips for testing. Each strip is to receive same mark
75°(not less)
37½°
12
9¼
½"
Each welder required to make two specimens No.1 horizontal. No.2 vertical.
Lap Welds
8"
6"
"L"
½"
7½"
½"x½" fillet
8"
Each welder required to make two specimens.
Bill of material for one welder
"B"-4 plates 9"x½"x12"
"L"-4 plates 6"x½"x8"
"F"- 4 plates 4"x1"x12" 4 plates 3"x¾"x6½"
Multiply by number of welders for total required.
Fillet Welds
3"x¾"x6½"
4"x1"x12"
4"x1"x12"
"F"
½"
9"
3"
3"
9"
4"
2½"
All fillets 2½" long Fill craters this specimen.
⅜"
⅜"
⅜"x⅜" fillet
⅜"
⅛"
Each welder required to make two specimens No.1 horizontal, No.2 vertical

Fig. 9. Specimens for Qualifying Welders

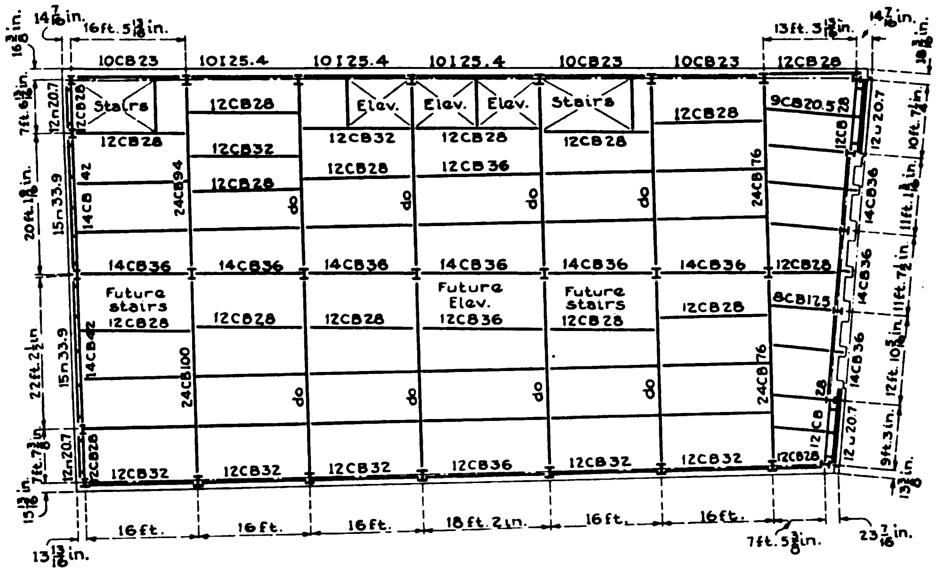

14⅞ in.
16ft. 5⅛ in.
13ft. 5⅛ in.
10CB23
10I25.4
10I25.4
10I25.4
10CB23
10CB23
12CB28
Stairs
12CB28
Elev.
Elev.
Elev.
Stairs
12CB28
9CB20.5
12CB28
12CB32
12CB32
12CB28
12CB28
12CB28
12CB28
12CB36
14CB36
14CB36
14CB36
14CB36
14CB36
14CB36
12CB28
Future stairs 12CB28
12CB28
12CB28
Future Elev. 12CB36
Future stairs 12CB28
12CB28
8CB11.5
12CB32
12CB32
12CB32
12CB36
12CB32
12CB32
12CB28
24CB94
24CB100
24CB76
24CB76
14CB142
14CB142
12CB28
15[33.9
15[33.9
12[20.7
12[20.7
14CB36
14CB36
do
16ft.
16ft.
16ft.
18ft. 2in.
16ft.
16ft.
7ft. 5⅛ in.
23 7/16 in.
13 11/16 in.
20ft. 1⅛ in.
22ft. 2⅛ in.
7ft. 6⅛ in.
7ft. 7⅛ in.
10ft. 7⅛ in.
11ft. 1⅛ in.
11ft. 7⅛ in.
12ft. 10⅛ in.
9ft. 3 in.

Fig. 10. Typical Floor Framing of the Edison Electric Illuminating Company's Boston Office Building

Qualification of Welders

The work was begun with three welders and a fourth was added later. The ability of each of the four men was established by qualification tests. Of other men who took the tests, some failed and others met the requirements but none of these were employed on the building as the four welders were found to be sufficient.

These qualifying tests to determine the welders' competency consisted of three types, Fig. 9: butt welds designated *B*, lap welds designated *L*, and fillet welds *F*. These three types are presented as follows in the order in which the specimens were prepared:

Lap Welds "L": Each welder was required to make two specimens, each consisting of two 6-in. by ½-in. by 8-in. plates with their 6-in. edges offset ½ in. These plates were clamped together and welded by hand along the 6-in. dimension. Upon cooling, the plates were broken by wedging at the free ends, and the broken weld examined for proper fusion with both plates; for density and texture of weld metal; for good penetration into the right-angle corner of the fillet; for freedom from gas holes, slag inclusions, and other defects.

It is scarcely necessary to add that when such plates are broken apart a good weld will break through the throat or minimum section, leaving a portion of the weld metal adhering to each plate throughout the entire 6-in. distance.

This test is so simple that it was given first and if the welder could not meet these requirements he was not permitted to proceed with the other tests.

Butt Welds "B": Two specimens, each consisting of two 9-in. by ½-in. by 1-ft. 0-in. plates were butt welded with a double Vee joint, one welded horizontally, the other vertically. After the weld reinforcement was removed by grinding or machining until the weld was reduced to the thickness of the plate, four or five test strips each 2 in. wide were cut from each specimen and tested in tension. The average tensile strength of each group of the two sample plates was not to be less than 45,000 lb. per sq. in.; and the tensile strength of the lowest in each group not less than 40,000 lb. per sq. in.

Fillet Welds "F": Each welder was required to make at least two samples as shown by *F*, Fig. 9, one specimen welded horizontally, the other vertically. On each side of the splice are a total of 10 in. of ⅜-in. fillet. In fairness to all parties concerned the welding inspector insisted that the fillets be ⅜ in. and each of 2½ in. length as shown. The 2½ in. dimension was made small to accommodate the testing facilities of the ordinary laboratory, but as a variation in length of a small amount may constitute a considerable percentage, the length of the fillet was as near 2½ in. as was possible to secure. Moreover, although in general it is best on the building to leave the craters normal (*i.e.*, not filled) in making these fillet specimens *F*, for sake of standardization each crater was filled to the full section of the ⅜-in. fillet, and the 2½-in. dimension included the filled crater. These specimens were tested in a tension machine, thus subjecting the welds to longitudinal shear, the ultimate value of which was a measure of the welder's ability. The two specimens were to average a total pull of at least 117,000 lb. corresponding to 44,000 lb. per sq. in., or 11,700 lb. per linear inch shearing value on the minimum or throat section of the weld; and the lowest value of the two was to be not less than 101,100 lb. total pull corresponding to 38,000 lb. per sq. in. or 10,110 lb. per linear inch of fillet. The lowest figure, 38,000, was so small that the welders whose minimum value did not at least reach that amount were rejected.

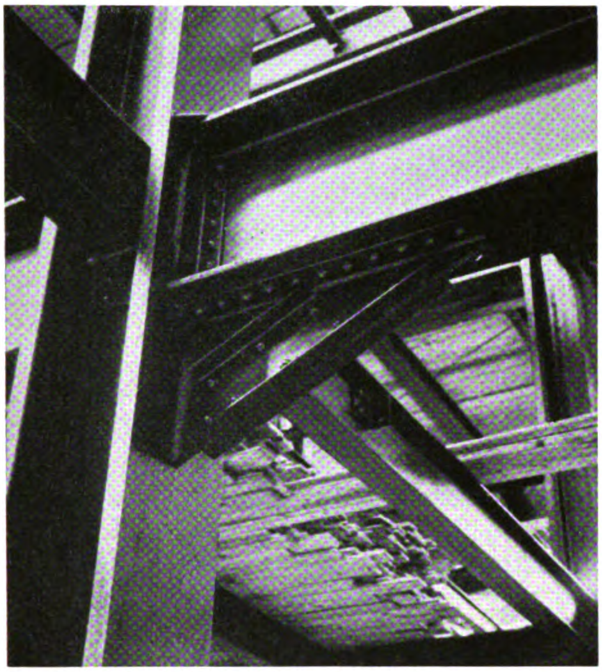


Fig. 11. Connection of 24-in. Girder to Column Flange, Showing Field Welding of Wind Bracing Bracket and End Connecting Angles to Column. (See also Fig. 4)

The highest ultimate tensile strength of the butt welds made by the seven welders who qualified was 56,500 lb. per sq. in. and the lowest was 43,700 lb. per sq. in. The average was 52,790 lb. per sq. in. This figure compares very favorably with 54,125 lb. per sq. in. which was the average value of tensile strength of four such specimens welded by the inspector, who had had much experience in welding.

Tests of the fillet-welded specimens made by the seven welders showed that the maximum load was 155,200 lb., equivalent to an average longitudinal shearing strength of 15,520 lb. per linear inch of fillet and corresponding to a shearing strength of 15,520 lb. divided by 0.266 sq. in., or 58,350 lb. per sq. in. of minimum (throat) section of the fillet. The minimum breaking load was 105,600 lb., equivalent to an average longitudinal shearing strength of 10,560 lb. per linear inch of fillet or 39,700 lb. per sq. in. on the throat section.

Butt-welded specimens with the weld reinforcement removed should give practically the same results whether welded in the horizontal or in the vertical position, and this was the case in this instance wherein the tensile strengths of the horizontally-welded and the vertically-welded specimens were 53,208 and 52,371 lb. per sq. in. respectively.

With fillet-welded specimens, however, one should expect to find a slightly greater average shearing strength for specimens made with the fillets welded vertically, because of the natural tendency for the molten metal in this position to form fillets which, instead of being triangular in cross section, have sections approaching a quarter of a circle. This was the case with the fillet-welded specimens of the qualification tests, the average shearing strength of all the specimens welded in the vertical position being 13,780 lb. per linear inch as compared with an average of 13,000 lb. per linear inch for all those welded in the horizontal position. The effect of this change in shape of the fillet's cross-section may be very marked. For example, the throat distance of a ⅜-in. quarter-circle fillet is 0.375 in. as compared with 0.266 in. for a ⅜-in. triangular fillet, an increase of 0.109 in. or 41 per cent of 0.266 in. One does not expect in ordinary welding to secure such marked differences as this but it is possible to do so by enlarging the throat. (In depositing vertical fillets the welding should proceed upward.)

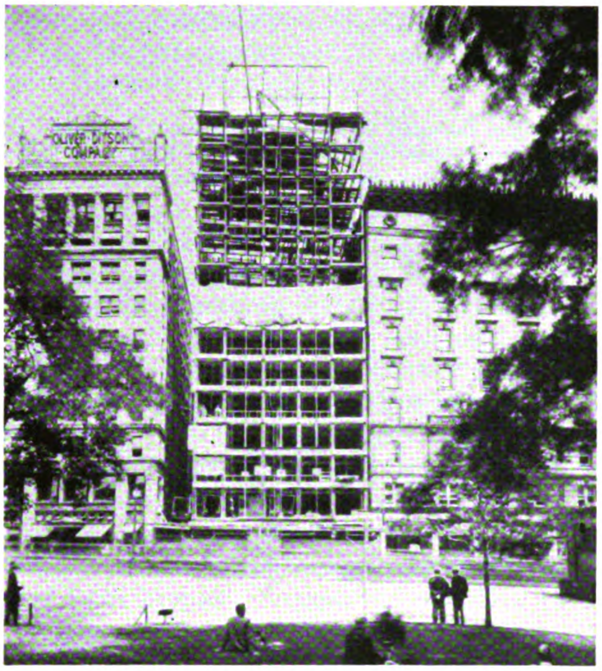


Fig. 12. Edison Electric Illuminating Company's Shop-riveted and Field-welded Office Building, Tremont Street, Boston (Mass.). Fourteen stories high. Contains 1314 tons of steel, of which 1050 tons are field welded

Before adopting the qualification test specimens *F* shown in Fig. 9, one should be sure that the testing machine available has sufficient size of opening in the grips to hold the specimens, sufficient clearance between the heads of the machine to accommodate the length at fracture, and sufficient capacity to break pieces of the size shown.

For this Boston building, at least twice a week each welder made a sample lap weld *L* which was broken for examination of the fractured weld.

Pertinent Data

Of the 60,514 linear inches of fillets, 51,921 in. were of ⅜ in., 7188 in. were of ½ in., and 1405 in. were of ⅝ in.; and the number of inches deposited by the four welders were 17,780, 16,644, 16,515, and 9575 respectively, the first three amounts being welded by the three men who worked during the entire welding period while the last amount was performed by the welder who started later than the others.

TABLE I

Comparison Between Chemical Analyses of Electrodes Used at Boston Edison Building with the American Welding Society's Standard Bare Electrodes for Hand Welding of Structural Steel

	MANUFACTURER'S ANALYSES		Our Analysis	American Welding Society's Grade E—No. 1B
	$\frac{5}{32}$ In.	$\frac{3}{16}$ In.		
Carbon.....	0.14%	0.14%	0.133%	0.13–0.18%
Manganese..	0.40%	0.45%	0.440%	0.40–0.60%
Phosphorus.	0.016%	0.018%	0.028%	Not over 0.04%
Sulphur....	0.034%	0.029%	0.024%	Not over 0.04%
Silicon.....	......	......	0.007%	Not over 0.06%

Approximately 80 per cent of the welding wire used was melted, the remainder being wasted as stub ends. However, these percentages are based on assumption, not on actual weighing.

Although a satisfactory chemical analysis alone is not a sufficient criterion to insure that an electrode or welding wire will give good results in service, it is nevertheless a very important item in selecting wire for welding structural steel. Consequently, it is the writer's practice to make chemical tests on electrodes, and Table I presents three analyses on the wire used in Boston, together with the composition of bare electrodes specified by the American Bureau of Welding for arc-welding structural steel by hand.

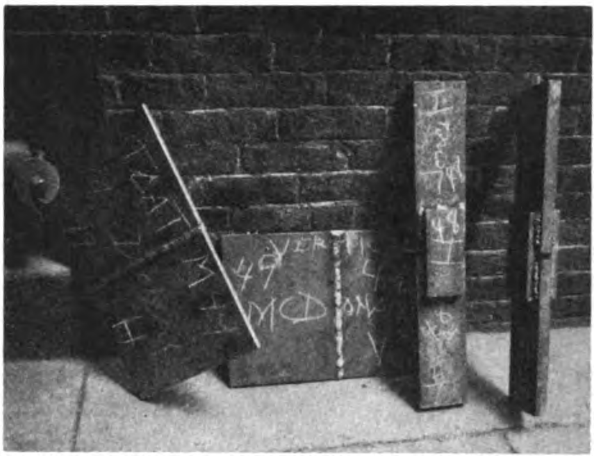


Fig. 13. Welded Plates for Qualifying Welders. The two butt-welded specimens at the left are to be cut into 2-in. tension test strips. The two fillet-welded specimens at the right are to be tested in tension to determine the longitudinal shearing strength of the fillets

It would be a rare coincidence were two steel building frames exactly alike. Certainly the details of construction vary greatly; and consequently Table II giving pertinent data for this building should be applied with extreme care in other cases. In studying this table,

TABLE II

PERTINENT DATA REGARDING FIELD WELDING OF BOSTON EDISON BUILDING

Electrode (total of used and wasted) $\frac{5}{32}$-in., 1500 lb.; $\frac{3}{16}$-in., 1100 lb.; total........	2,600 lb.
Electrode melted (assumed 80% of total)..	2,080 lb.
Electrical energy used..................	6,120 kw-hr.
Total structural steel...................	1,314 tons
Structural steel welded..................	1,050 tons
Actual welders' time (man-hours)........	1,205½ hr.
Total length of ⅜-in. fillet..............	51,921 linear in.
Total length of ½-in. fillet..............	7,188 linear in.
Total length of ⅝-in. fillet..............	1,405 linear in.
Total length of all fillets................	60,514 linear in.
Fillet per ton of steel in building, 60,514/1314	46.05 in.
Fillet per ton of steel welded, 60,514/1050.	57.63 in.
Fillet deposited per welding man-hour, 60,514/1205.5.......................	50.2 in.
Fillet deposited per man per 8-hour day...	33 ft. 6 in.
Fillet deposited per pound of wire used and wasted, 60,514/2600.................	23.27 in.
Fillet deposited per pound of wire melted, 60,514/2080........................	29.09 in.
Fillet deposited per kw-hr., 60,514/6120...	9.9 in.
Electrode melted per kw-hr., 2080/6120...	0.34 lb.

Electrical energy required to melt one pound of electrode, 6120/2080...............	2.94 kw-hr.
Welding man-hours per ton of steel in building, 1205.5/1314.....................	0.917 hr.
Welding man-hours per ton of steel welded, 1205.5/1050.........................	1.148 hr.
Electrode melted per ton of steel in building, 2080/1314......................	1.582 lb.
Electrode melted per ton of steel welded, 2080/1050..........................	1.98 lb.
Electrode melted and wasted per ton of steel in building, 2600/1314...........	1.98 lb.
Electrode melted and wasted per ton of steel welded, 2600/1050..................	2.48 lb.
Electrode melted and wasted per hour per welder, 2600/1205.5.................	2.16 lb.
Electrode melted and wasted per linear inch of fillet, 2600/60,514................	0.043 lb.
Electrode melted per linear inch of fillet, 2080/60,514........................	0.0343 lb.
Electrical energy required per ton of steel in building, 6120/1314...............	4.66 kw-hr.
Electrical energy required per ton of steel welded, 6120/1050....................	5.83 kw-hr.

it should be remembered that the provisions for wind resistance are an important element in the amount of welding; that all secondary as well as primary beams are field welded here, whereas in many other cases the secondary beams may be bolted; and finally, that of the total steel of 1314 tons, 1050 tons consisted of columns and beams welded together in the frame itself, whereas 264 tons were foundation cantilever beams and grillages devoid of welding.

For a building frame similar to that of the Edison Building and of a known tonnage of steel, it is possible with the aid of Table II to estimate the number of pounds of electrode required, the linear inches of fillets, the amount of electrical energy, and the number of man-hours required for welding.

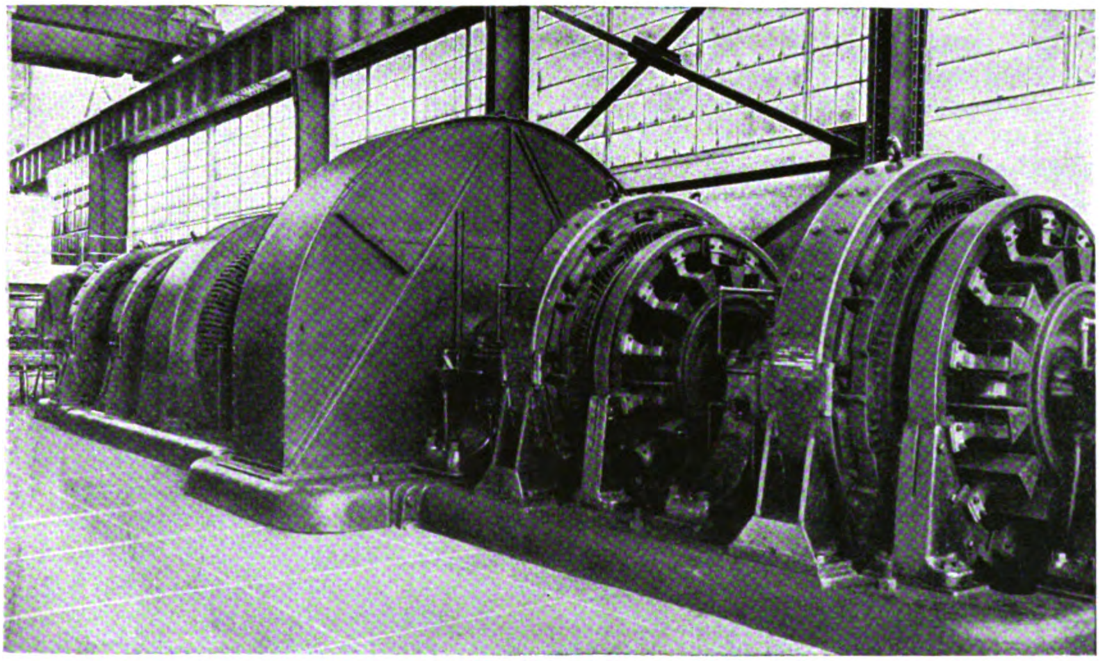
Inspection

The inspection of welding consisted of assisting in the qualification tests of welders, in making certain that the proper electrodes and current were used, verifying the sizes, lengths, and locations of completed welds in accordance with the plans, examining each weld for quality, testing welders during the progress of the work, and in making daily reports covering in detail the number of inches of fillet for each connection deposited during the day, together with the location of each weld and name of the welder making it. The inspector was an experienced welder and previously was instructor of welding at the General Electric Company's River Works, Lynn (Mass.).

The question is frequently asked: "What do you do when a poor weld is found?" It should be cut out either by hand or by a pneumatic tool and the joint should then be rewelded. In the Edison Building this was not necessary except in one case where an error occurred in setting a column base at an incorrect elevation, which caused a few beams to be welded at incorrect heights. When this mistake was discovered the welds were cut out, the column base set correctly and the beams rewelded.

Whidden-Beekman Engineering Company, 100 Arlington Street, Boston, were designing and supervising engineers in charge of the structural steel, floor system, and foundations. The writer and his associates, Carson and Carson, 22 South Fifteenth Street, Philadelphia, were consulting engineers on welding design and execution and inspection thereof. W. A. and H. A. Root of Boston were the general contractors. American Bridge Company fabricated the steel, which was erected by Daniel Marr and Son of Boston and welded by Leake and Nelson of Bridgeport. Bigelow, Wadsworth, Hubbard, and Smith, 11 Beacon Street, Boston, were the architects. George E. Seabury represented the Edison Electric Illuminating Company.

For Power Supply to Steel-mill Motors



A flywheel motor-generator set supplying power to two reversing motors driving 44-in. blooming and 36-in. rail-roughing mills. The set includes an 8000-hp. induction motor, two 3000-kw. and two 2200-kw. generators and a flywheel

The Versatility of Application of Selsyn Equipment

By R. A. CORBY

Aeronautics and Marine Engineering Department, General Electric Company

This is the third recent REVIEW *article dealing with Selsyn mechanisms. As a means of indication they were used at the Panama Canal* (GENERAL ELECTRIC REVIEW, *January, 1914). The present-day equipment for both indication and control was described in our September issue and its application to the oil-refining industry in the July issue. This article is a survey of the various fields of application.*—EDITOR

SELSYN devices are self-synchronous machines (Fig. 1) for actuating remote operating and signalling mechanisms. A Selsyn machine, then, is a remote control device. It is not a generator, nor a motor, nor a transformer, because its primary function is *not* the *conversion of energy* from one form to another. However, a Selsyn unit performing a specific operation is often called a Selsyn generator or a Selsyn motor to distinguish between a transmitter and a receiver; and differential Selsyn machines, because of their peculiar operation, are sometimes referred to as rotating transformers.

The service to which Selsyn equipment is better adapted than any other device is the *transmission of angular motion* accurately over long distances by electrical means.

Thus the Selsyn mechanism might be called a "long-distance anglemeter" although its range of operation may be a few feet as well as several miles. Where remote control by angular displacement is desired, or where accurate indication, recording, or signalling is necessary, Selsyn devices are most practical because of their simplicity, dependability, durability, and accuracy.

Naturally, therefore, Selsyn equipment has been applied in a wide field of usefulness. In this article, typical installations will be described, a general survey of which will suggest future utility.

Panama Canal Installation

It is well, at this point, to consider some of the earlier applications of Selsyn devices. Compared with the majority of the devices in the electrical industry, Selsyn machines are infants. The first installation of Selsyn equipment big enough to "toddle along under its own power" was built in connection with the control of the locks in the Panama Canal. (The trade name "Selsyn" had not yet come into use, but the machines were essentially, if not in detailed design, the same as present-day Selsyn devices. They were then known as "position indicators.")

Even now, the installation at the Panama Canal is one of the outstanding achievements in remote indication and control, and one of the most interesting applications. This is due largely to the number and variety of tasks to which the system was fitted.

Electrical control was chosen in preference to any other type mainly because it was the only system that would make it possible to control a set of locks from a central position and at the same time provide for the miniature reproduction of all operations of the locks in the control room. In meeting the latter condition, Selsyn devices were used extensively and successfully. The more specific adaptions are briefly described in the following paragraphs.

The top of a lock control board is a miniature plan of the lock itself so that a glance will show the operator at all times the exact positions of the various miter gates, rising stem gate valves, water levels, chain fenders, guard valves, miter-forcing machines, and cylindrical valves. It is necessary that the first five of these be indicated throughout their entire travel; therefore Selsyn mechanisms are used as the indicators. In the other operations, it is necessary to show only the two limiting positions. Signal lights, or something similar, are used for this purpose.

The position of each set of miter gates (main lock gates) is shown on the control board by means of a pair of aluminum leaves or pointers which are shaped to correspond to the plan view of the lock gates themselves. These leaves are operated through bevel gears by a pair of Selsyn motors located under the control board. These, in turn, are actuated electrically by two Selsyn transmitters, one being driven by each separate gate. When the large gates open, the miniature ones, perhaps half a mile away, do likewise, requiring only three small wires to transmit the signal.

The rising stem gate valve index has been likened to a miniature elevator in which the car is used to indicate the vertical position of the valve. The motion of the valve is transmitted mechanically to a Selsyn generator which actuates a Selsyn motor located under the control board at the proper index. On the shaft of the motor is a drum over which rides the cord that is connected to the "elevator car." This "car" is equipped with reflectors which throw the light from lamps below the board and inside the indicator onto the glass-covered index. The resulting sharp line of demarkation between illuminated and dark portions of the indicator shows accurately how far the valve is open. A totally dark indicator means the valve is closed. A totally illuminated one shows that the valve is open.

The water level indications required much greater accuracy than could be obtained by the 178 degrees of rotation (which was at the time the standard travel) of a Selsyn transmitter (Fig. 2). In fact, it was desired to indicate a 50-ft. water level to within five-eighths of an inch. To secure this degree of accuracy, it was necessary to rotate the transmitter through ten revolutions. This, however, made it possible for the receiver and transmitter to be in phase in 20 different positions, only one of which would give the correct reading. Accordingly, a second receiver was provided, this one to have the normal 178 degrees travel. It was arranged to operate an aluminum ball on a chain similarly to the operation of the stem gate valve indexes. The ball was arranged to pass through the hollow cylindrical index of the other receiver. The latter index provides the fine indication and its length is such that so long as the ball is within the limits of the cylindrical index, the reading could be depended upon to be the correct one. The cylinder itself is used as the index without the aid of the lamps or reflectors as used in the gate valve indicators.

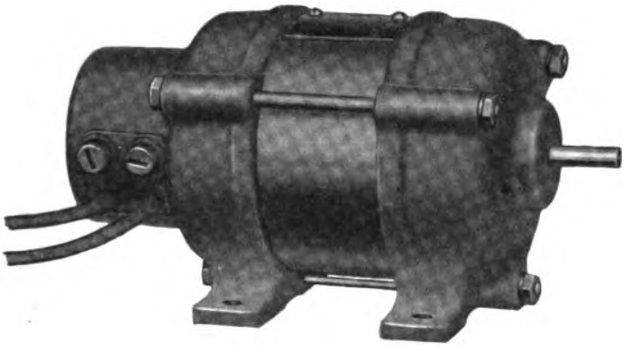


Fig. 1. A Selsyn Generator

Heavy fender chains are stretched across the locks in front of all mitered gates to protect them from being rammed by the ships. These are represented on the control board by small aluminum chains in the same relative positions as the large ones. Just as the large chain is lowered into a slot at the bottom of the lock, so the small chain is lowered into a slot in the top of the board. The ends of the miniature chain are fastened to semaphore arms which are connected by means of adjustable links to arms on segmental gears. These gears mesh with the driving gears on the Selsyn receivers. The receivers, in turn, are actuated by the Selsyn transmitters which are driven by the chain-hoisting pistons.

The guard valve positions are indicated in practically the same manner as the stem gate valve positions.

This brief exposition of the various parts of the control of the Panama Canal locks affords some idea as to the adaptability of Selsyn indicators to widely varied uses.

Automatic Control for Hydroelectric Plants

A good example of the use of Selsyn equipment for automatic control is their adaptation to forebay float regulation of hydraulic turbines. In a number of hydraulic power plants in California and Colorado provision is made to control, in this way, the load on the turbines. In general the scheme used is as follows:

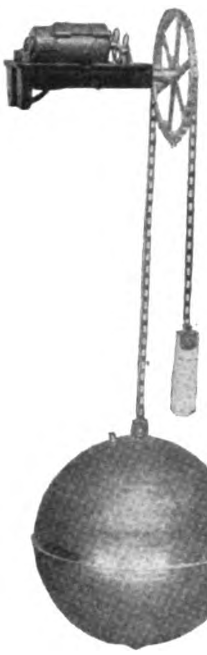


Fig. 2. A Selsyn Transmitter for Indicating Water Level

Changes in water level in the forebay actuate a Selsyn transmitter which drives a receiver in the power house. This receiver, through differential gearing, operates relay switches which control a reversible electric motor. The motor, in turn, drives the mechanism used to adjust the needle nozzles of the turbine units. Thus any appreciable change in the forebay water level will vary automatically the load of the turbines.

Numerous other Selsyn equipments may be used to economic advantage in and about power plants, some of which will be enumerated later.

Bascule Bridge Indication

For angular indication, Selsyn mechanisms are the ideal apparatus. With the help of these small machines a lift bridge operator can tell simply by looking at an indicator (Fig. 3) the exact position of each section of the movable parts of the bridge. The operating room need not even be within visual range of the bridge. In smoke, or fog, or storms the operator has no difficulty in determining the positions of the leaves.

Elevator Position Indicators

Frequently Selsyn devices are used as auxiliary apparatus in elevator installations. In an installation at St. Johns College, Brooklyn (N. Y.), they are used as follows in the indicating system which shows the position of the elevators at the various floors: To the sheave of each of the four elevators, through a chain and a gear train, is attached a Selsyn transmitter. Each transmitter (Fig. 4) operates a receiver at the indicating control board. The receivers, in turn, drive long, vertical worm gears upon which are mounted the indicators. The relative positions of these indicators along the respective worm gears shows (Fig. 5) just where the elevators are at any time.

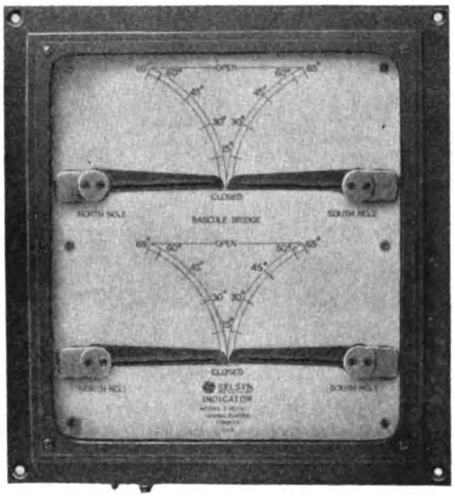


Fig. 3. An Indicator for a Bascule Bridge

On either side of each vertical worm gear is a narrow panel containing numerous small electrical contacts, one set for each floor in the building. As the elevator reaches a certain floor, its position indicator, through the Selsyn arrangement, is driven to the correct point on the panel. A set of contacts are thereby closed enabling a relay circuit to be completed by a push-button at the floor where a passenger is waiting.

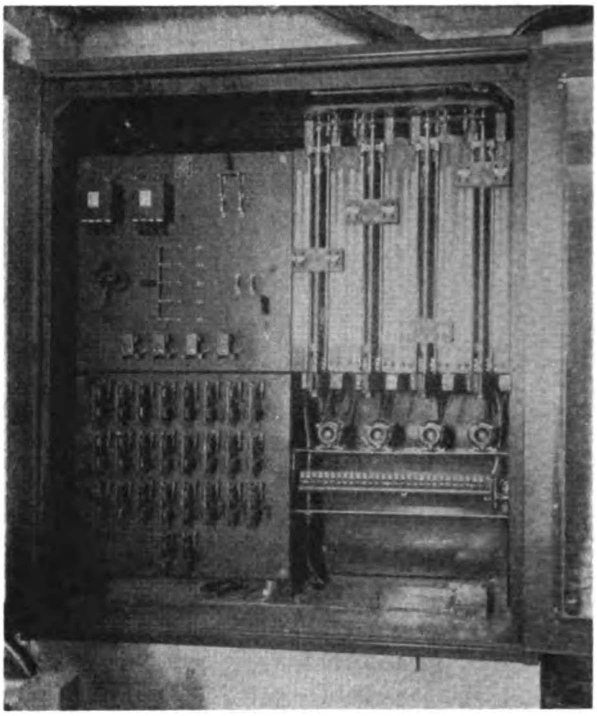


Fig. 5. Receiver Equipment for Elevator Indicator

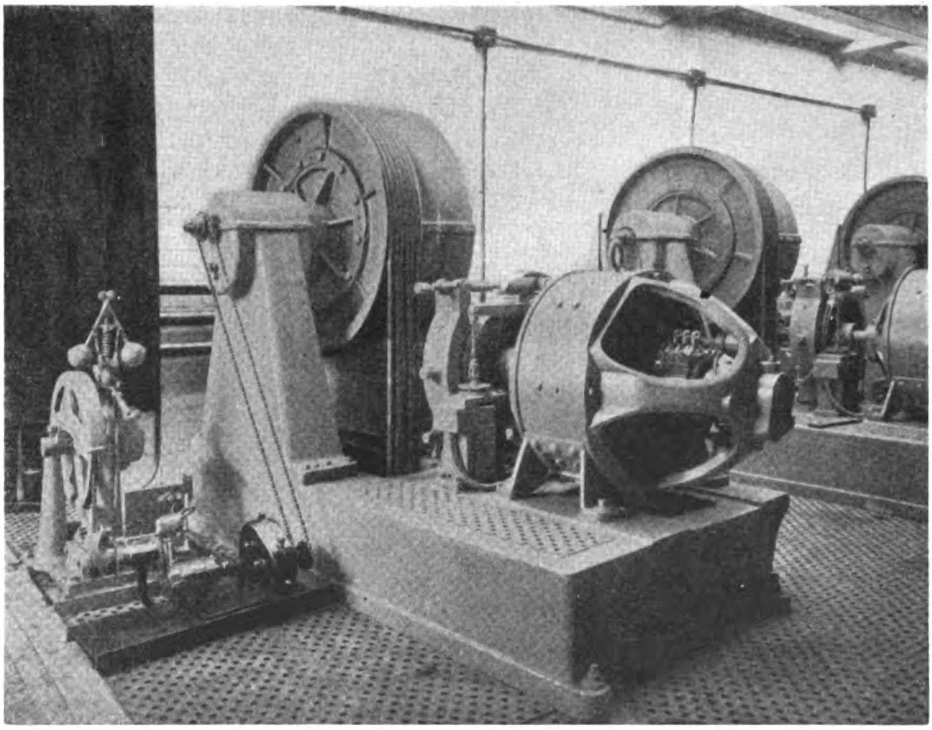


Fig. 4 Transmitter Equipment for Elevator Indicator

When the elevator comes within two floors of the one where the passenger is waiting the relay causes the indicating lamp to light, showing that the elevator is near.

Something New in Stage Lighting Control

In Chicago, where superlatives are aptly used to describe a great many things, another may be added in describing the new Civic Opera House, which was opened in November, 1929. Beside many other remarkable features, the vast stage-lighting scheme and its control system are without parallel.

The old system of lighting required a large switchboard, perhaps 40 ft. long by 8 ft. high, which was located back-stage. A great deal of physical effort and many complicated mechanical devices were necessary to effect the intricate light effects desired. Further, the operator could not see, except indirectly, the stage and the effects he was producing.

The Chicago Civic Opera stage is lighted by 141 individual circuits of lights. Each one contains lights of only one of the four colors and the dimmers for each circuit are controlled by a Selsyn receiver. Each circuit could be controlled individually, but that would require the manipulating of too many knobs by the operator. Instead, a method of grouping the circuits according to color, location, or function, has been devised. For instance, one group many comprise all the blue floodlights, and another all the amber pocket lights, and so on.

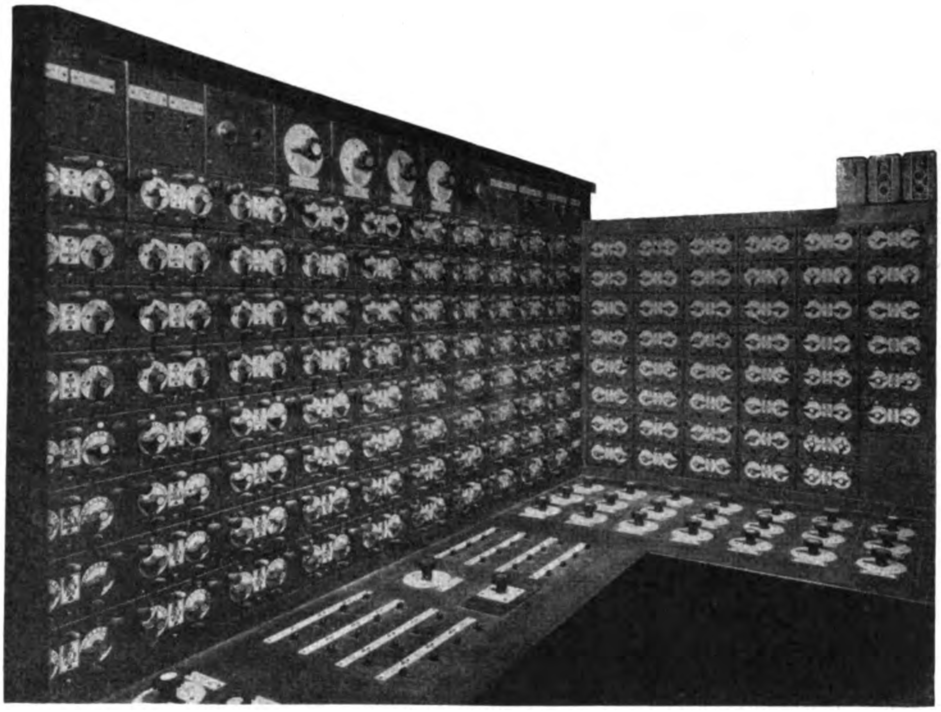


Fig. 6. Lighting Director's Control Board in the Chicago Civic Opera

The lighting director is stationed in front of the stage, along with the orchestra leader. Here (Fig. 6), looking over the footlights from his position in a small room directly in front of the orchestra pit, he manipulates the 1250 kilowatts of lighting energy, supplying bank-lights in the wings on either side of the stage, border-lights directly above the stage, spotlights, bunch-lights, footlights, and floodlights. Each of these groups contains lights of four different colors, amber, red, blue, and white. All are controlled by means of the Selsyn operating system especially designed for this installation.

The lighting operator has in front of him, and at either side, rows of dials, knobs, tumbler switches, indicating lights, etc., mounted on the control panel. By manipulating these he can "set up" the lighting effect to be used in the next scene or the next change of lights. Then at the proper time he can produce this effect, and at the proper speed of change, merely by turning a single knob.

There are 33 of these groups, each one being controlled by a group-master differential Selsyn generator, whose size depends upon the number of Selsyn receivers it operates. In addition, there are four large differential Selsyn generators acting as color masters (Fig. 7), each one controlling all the lights of one color, no matter where located. Finally, a large grand-master Selsyn generator (Fig. 8) is connected to the color masters so that all 141 circuits, or as many as desired, may be operated simultaneously.

The knobs on the small Selsyn receivers, the group masters, the color masters and the grand master are all on one control board within reach of the operator, who can thus manipulate any single receiver, any group, any color, or all lights at once.

The Selsyn receivers effect the actual control of the lights by operating induction voltage regulators (Fig. 9), which vary the voltage on the grids of Thyratron tubes. These tubes, in turn, change the saturation of reactors in the lighting circuits.

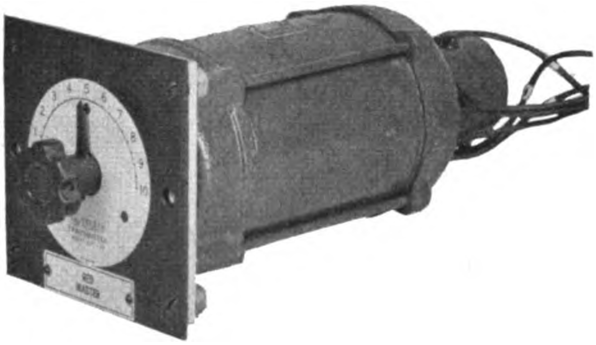


Fig. 7. Differential Selsyn Generator Color Master

The Versatile Selsyn Device

Having described typical installations of indicators and control devices, it is feasible to list some of the uses to which Selsyn apparatus has been adapted with decided advantage.

Selsyn mechanisms are being used as remote control devices in:

(1). The control of frequency
(2). The control of variable-speed motors
(3). The automatic control of water-wheel governors
(4). The automatic control of liquid levels (Fig. 10)
(5). The automatic control of valves and gates
(6). Theatre stage-lighting control
(7). The control of decorative lighting.

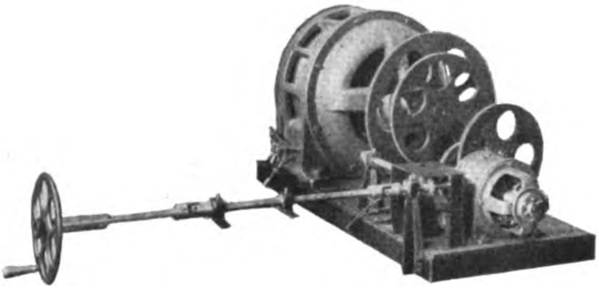


Fig. 8. Grand-master Selsyn Generator Controlling Color Masters

They are used as remote indicators for:

(1). Power-station loads
(2). Transformer taps
(3). Compound vectors
(4). Furnace charge heights
(5). Arrivals and departures of trains
(6). Power-plant signals, steel-mill signals (Fig. 11), signals aboard ship from pilot house to engine room, and signals of many other types
(7). Positions of valves and gates
(8). Liquid levels (Fig. 12) and gas pressures
(9). Railroad turntables
(10). Positions of lift bridges, elevators, turbine governors, frequency-changer stators, field rheostats, water-wheel governors (Fig. 13).

Some Future Possibilities

The limit of possible uses of Selsyn apparatus has by no means been reached. They are being adapted continually to new types of installations, a trend to be expected for some time to come.

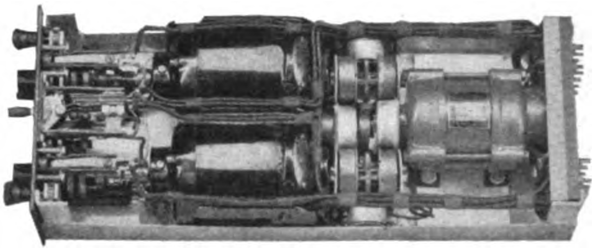


Fig. 9. Voltage Regulator for Chicago Civic Opera

An interesting possibility for the future is use of Selsyn machines in the control of electric locomotives and electrically-driven ships. In the present system of accelerating locomotives, the controller cuts out resistors in a step-by-step sequence, producing acceleration varying by intervals established by the control; but with Selsyn-device-operated Thyratron control, the acceleration will be perfectly even and totally automatic. The load curve will be a smooth line from zero current to the point of full voltage across the motors.

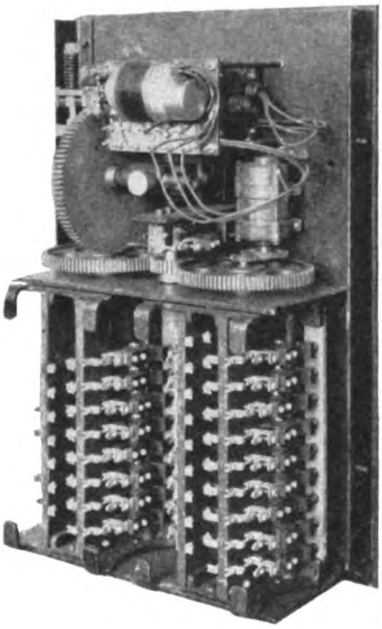


Fig. 10. Master Switch for Pumping Equipment

Another application that will come with the production of still smaller Selsyn apparatus is the remote control of radio receiving sets from two or three convenient places throughout the home. For instance, a small knob under the dining room table will make it possible for one at dinner to tune the radio set in the living room at will.

Still another interesting possibility, or rather probability, is the expansion of Selsyn equipment installations in the realm of lighting control.

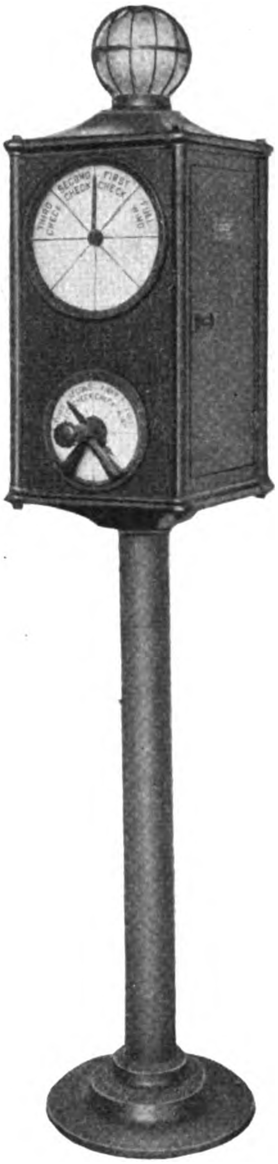


Fig. 11. Signal Pedestal for a Steel Mill

The newest, and by far the most attractive type of interior decoration is that of mobile varicolored light, produced by what is known as the Colorama system. This mode of exploiting color schemes has so many advantages over mere paper and paint that its popularity will grow rapidly when its merits can be properly displayed. A long step in this direction has been made in connection with the decorating of the ballroom of the new St. George Hotel in New York City. This ballroom has a floor space of 9500 sq. ft. and is 30 ft. high. The walls are windowless and are painted a flat white. A scheme of cones, flutes, lamps, and color media makes possible innumerable effects of light, shadow, and color. The various effects are produced by varying the intensity of the numerous banks of different colored lights.

Although another type of control was employed in the St. George Hotel installation, this affords a very good example of the type of lighting that, in the future, will be manipulated by self-synchronous apparatus. Where a definite cycle of light effects is satisfactory, or where but a single circuit is involved, Selsyn control offers but a few outstanding advantages. However, when a Selsyn-Thyratron system is used to control an arrangement of this kind, different effects may be produced at will through the control of any number of circuits. In the foregoing installation there are but four colors of lights: red, green, blue, and white, but the dimming and blending that would be possible with Selsyn-Thyratron control would make the variation of shades practically limitless.

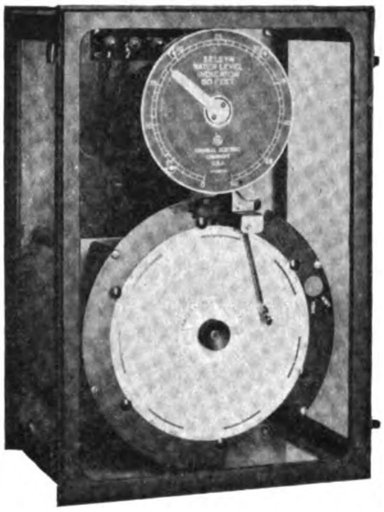


Fig. 12. Water Level Indicator with Recording Chart

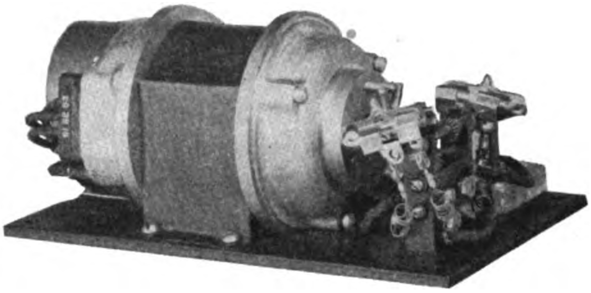


Fig. 13. Differential Selsyn Mechanism with Mercury Switch

Starting Induction-Type Motors from Systems of Limited Capacity

Outline of Method of Analysis—Alternator Characteristics—Induction Motor Characteristics—Effects of Various Starting Conditions—Calculated Curves—Empirical Rules—Derivation of Formula

By W. C. JOHNSON, Jr.
Industrial Engineering Department, General Electric Company

WHEN induction-type motors are to be started from systems of limited capacity the question of voltage regulation is of prime importance from several viewpoints. Among these are the possibility of never getting sufficient torque to start the motor thrown on, the flickering of lights, the dropping out of undervoltage relays, and the stalling of other induction or synchronous motors already connected.

The results of the analysis which follows are the accompanying voltage regulation curves (Figs. 5, 6, 7, and 8) and an exposition of methods whereby almost any case within the stated limits and with known constants can be estimated in a straightforward and simple manner. The curves should have wide application on account of the generalizations made; but where the actual operative conditions are different from those assumed for the graphs (since it has been impossible to include all), recourse may be had to the methods of calculation here outlined. This article will be limited to consideration of a-c. polyphase systems.

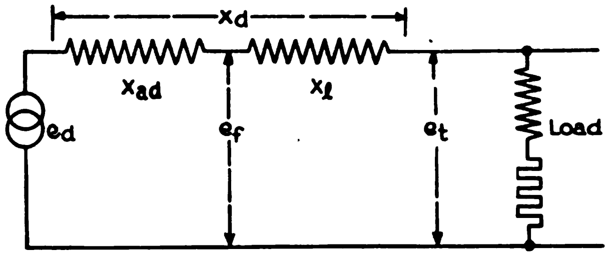


Fig. 1. The Equivalent Circuit of a Loaded Alternator

One-line diagrams and per unit quantities will be used throughout. The first or one-line diagram can be thought of as representing one of the several phases; per unit quantities are per cent quantities divided by the factor 100, and embody all the advantages that a per cent system does in the matter of representing by general constants a whole group of machines with similar characteristics but with different ratings.

It should be kept in mind always that unit voltage is rated line-to-line or line-to-neutral voltage, that unit current is full-load current, and that unit impedance is phase impedance, which in the case of 3-phase systems assumed to be connected in Y is equal to the rated line-to-line voltage divided by $\sqrt{3}$, divided by the full-load current.

In all cases, the unit base will be that of the generating system rather than of the motors, which necessitates the rather obvious use of the ratio of alternator current or kv-a. to motor current or kv-a. in changing impedances and currents from the motor unit base to the alternator unit base or *vice versa*.

The assumptions that will be included will in most cases be stated as the development proceeds, but it will be well to mention that the assumption of round-rotor alternators will be made throughout. It has been shown(1) that the main effect of salient poles is to reduce the angle of shift between the pole axis and the rotating field corresponding to line voltage, and that the field excitation required and the voltage drops experienced are very nearly the same as for a round-rotor machine. Since we are concerned mainly with these latter, we will not use the "two-reaction theory" connected with salient pole construction.

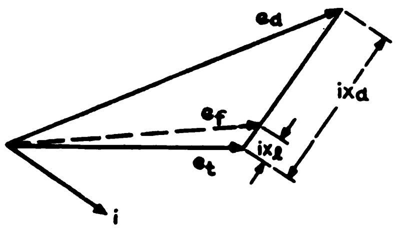


Fig. 2. Vector Diagram for a Loaded Alternator

Alternator armature resistance is assumed to be negligible, since it is such a small quantity in comparison with the machine reactance that this assumption makes relatively little error.

The Alternator

Whenever alternator is mentioned in this article, a picture should be held in mind (Fig. 1) of a generated voltage (e_d) and a reactance called synchronous reactance (x_d), the latter being the sum of a true or leakage reactance (x_l) and an equivalent reactance (x_{ad}) due to armature reaction. This way of regarding an alternator is most graphic, and capable of being used for quite accurate computation. Without saturation, the excitation required when the machine is loaded is proportional to (or in per unit terms would be equal to) e_d, which is the terminal voltage e_t plus the ix_d drop, taken with the proper vectorial relationship (Fig. 2), and e_d would be the voltage obtained with removal of load.

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(1) Appendix D of "Synchronous Machines I and II," by R. E. Doherty and C. A. Nickle. *Trans. of the A.I.E.E.*, June, 1926, pp. 912-947.

With the inclusion of saturation we will have a complete enough picture of an alternator to calculate all steady-state conditions as accurately as is necessary for our purpose. To include saturation we start by assuming that the terminal voltage represents the actual flux which is being cut by the stator conductors. The flux in the field poles, where most of the saturation exists, is greater than e_t (thinking here in terms of per unit of normal) by the amount of leakage. Thus we say that e_f, the "voltage behind the leakage reactance," measures the flux in the field poles. The rest of the reactance drop, ix_{ad} is the opposition of two equal magnetomotive forces, one due to the field ampere-turns and the other due to the armature reaction; and no actual flux exists due to these. Actually there is leakage flux in the armature teeth, but we assume this to be negligible.

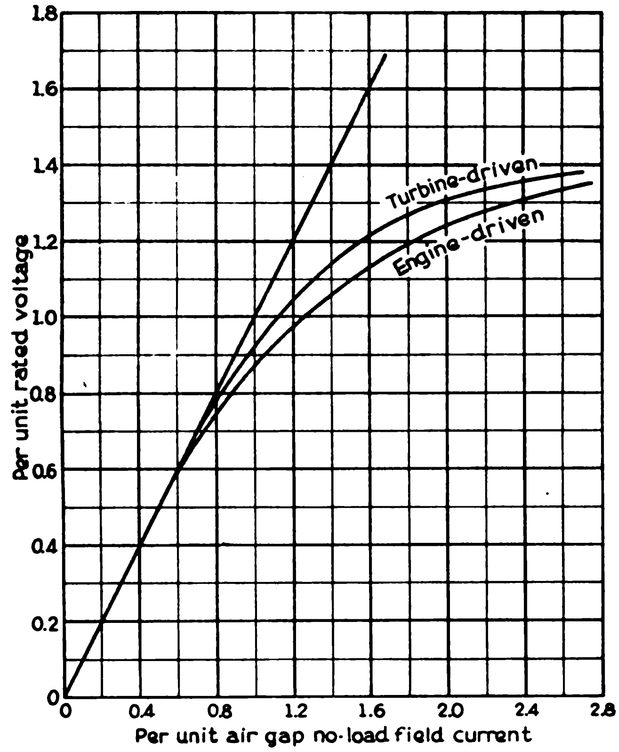

Fig. 3. Average Alternator Saturation Curves

A certain amount of saturation corresponds to each value of e_f, the flux in the pole, and we simply read the extra amount of excitation required for this saturation from the no-load saturation curve (Fig. 3) and add this to e_d to find the total excitation required.

An average saturation curve for engine-driven alternators is given, from which we will calculate, as an illustration, the full-load excitation required for such a machine, and also the rise in voltage when load is removed. Looking at the machine vector diagram, with full-load, 0.8-p-f. current on a per unit basis $(0.8-j\,0.6)$, and a synchronous reactance of $j\,1.1$ we may say that without consideration of saturation, the excitation voltage e_d is $e_t+ix_d=1.0+(0.8-j\,0.6)\,j\,1.1=1.0+0.66+j\,0.88=1.88$ scalar value. The values of synchronous reactance ($j\,1.1$) and leakage reactance ($j\,0.25$) that we assume are high average values for an engine-driven alternator and are surprisingly uniform for machines of this type.

The "voltage behind the leakage reactance" which measures the actual flux in the field poles and hence the amount of saturation, neglecting the small amount of saturation elsewhere, is $e_f=e_t+ix_l=1.0+(0.8-j0.6)\,j\,0.25=1.0+0.15+j\,0.2=1.17$, scalar value.

With this value of e_f we go to the average saturation curve and read the excess ampere-turns required for saturation, giving $1.74-1.17=0.57$.

The total excitation needed is $1.88+0.57=2.45$.

If load is removed, we find directly from the saturation curve that we obtain 1.31 per unit rated voltage with this excitation. The regulation would thus be 31 per cent.

If x_d and x_l in per unit terms are to be determined for any particular machine, we may find them as in the following.(2) The value of x_d in per unit terms is the field current (I_s) required for rated current with a 3-phase short circuit at the machine terminals, divided by the field current (I_g) required, with no saturation, for rated voltage and no load.

$$x_d=\frac{I_s}{I_g}$$

The leakage reactance (x_l) is the synchronous reactance less the "reactance" of armature reaction x_{ad}, the latter being found from the design sheet as the field current to neutralize (with no leakage) the demagnetizing ampere-turns produced by full-load armature current. In other words, we divide the ampere-turns of full-load armature reaction by the field turns and call this I_{ar}; then

$$x_{ad}=\frac{I_{ar}}{I_g}$$

and

$$x_l=x_d-x_{ad}$$

Transient reactance will be referred to at a later time and will complete the picture we wish to retain of a synchronous machine. The transient reactance is a concept introduced from the constant-linkage theorem, which states that for instantaneous changes in electromagnetic circuits, all the "inertia" of the system is in the flux linkages and that whatever else may change instantaneously, flux linked with a closed circuit may not.

It has been shown that the leakage reactance measures the flux in the poles and it is natural to assume that it is this, the voltage (flux) behind the leakage reactance in the vector diagram, that remains constant for instantaneous changes. This is correct except that not quite all the flux is linked with the generator circuits under consideration, and a little less short-circuit current is produced than would be inferred from this simple assumption.

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(2) "The Reactance of Synchronous Machines," by R. H. Park and B. L. Robertson, *Trans. of A.I.E.E.*, April, 1928, pp. 514-536.

The reduction in short-circuit current from that figured from the leakage reactance means that we must use a slightly higher value than leakage reactance for the transient reactance.

If groups of alternators are to be considered instead of a single alternator, their reactances (upon a common kv-a. base) are to be combined in parallel to give an equivalent single machine. Some average saturation curve may be assumed.

Transmission lines and transformers can usually be included with sufficient accuracy as series impedances.

The Induction Motor

The picture of an induction motor that we wish to use in this analysis is that of a reactance, a fixed resistance, and a resistance that varies with speed, all in series (Fig. 4).

The more complete picture of an induction motor given by a diagram which includes magnetizing reactance and two or more parallel circuits(3) is more complicated than we will need, since we consider only a motor during the starting period, when without much loss in accuracy all the reactance and resistance may be lumped into an equivalent three. This assumes a simple single-winding rotor. That an induction motor is a fixed impedance for a given speed is perhaps the most important point here. The following common types of motors are considered in this article:

(1). Squirrel-cage, normal-torque, normal-current (*K*).

(2). Squirrel-cage, high-starting torque, high-rotor resistance (*KR*).

(3). Double squirrel-cage, normal-torque, low-starting current (*KF*).

(4). Double squirrel-cage, high-starting torque (*KG*).

(5). Synchronous, with squirrel-cage winding, medium-speed (*TS*).

In many of our calculations we assume that the voltage dip comes while the induction motor is standing still, since this is the worst condition; and for this case the slip is unity and r_2/s is r_2. The torque in per unit terms that the rotor exerts for acceleration or load can be shown to be $i_2^2 r_2/s$. Note at this point that if one induction motor is already connected to an alternator when another is thrown on, the current taken by the motor already running falls at first in proportion to the fall in voltage, but will quickly increase until the $i^2 r_2/s$ is equal to the load torque, so that the current drawn by a motor running loaded finally becomes larger with reduced voltage than with full voltage.

Saturation may be sufficient to reduce the reactance in our picture of an induction motor by as much as 15 per cent because of the heavy currents which are forced through it when starting with full voltage. The plain low-resistance squirrel-cage motor has more saturation than the other types, since the starting currents are greater. When starting with less than full voltage, the amount of saturation would be reduced and the motor reactance that is used to figure voltage regulation should be increased.

However, we will not allow for saturation in induction motors because it is so very indeterminate and because neglecting it will put our figures even more on the safe side, when the true full-voltage starting current is used and is reduced directly in proportion for lower voltages applied. It is interesting to note in this connection that the use of an autotransformer reduces the saturation, but that this reduced saturation in the motor is somewhat offset, when viewed from the alternator, by the magnetizing current drawn by the autotransformer itself.

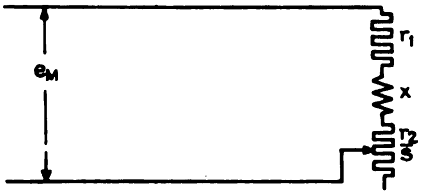

Fig. 4. Equivalent Circuit of a Simple Squirrel-cage Induction Motor When Starting

The theoretical transformer tap to give maximum motor voltage and hence maximum starting torque with indefinitely long starting time and fixed excitation is that which will make the equivalent starting impedance of the motor (the actual impedance increased by the square of the ratio of transformation according to the ideal transformer concept) equal in scalar value to the synchronous reactance of the alternator. No saturation and a perfect transformer are assumed. This relation for maximum torque is obtained by writing the equation for power under the given conditions, differentiating it with respect to the ratio of transformation and equating the derivative to zero.

This theory of the best compensator tap needs to be used with a great deal of caution, on account of alternator saturation and on account of the fact that it is not a very "sharp" maximum, but it should help to indicate when the compensator is being used to full advantage from the standpoint of motor torque.

If it is not considered accurate enough to make use of the perfect transformer concept, greater accuracy is obtained by representing the autotransformer by a parallel and a series reactance (magnetizing and leakage reactance). Average values of these on the basis of full-load motor current might be five per unit for the parallel reactance, giving 20 per cent current for excitation, and 0.025 per unit for the series reactance, giving approximately a six per cent voltage drop for a stalled three-phase squirrel-cage motor.

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(3) For example, see V. Karapetoff: *The Magnetic Circuit*, McGraw-Hill, New York.

From the relations given for polyphase induction motor torque it is easily shown that the maximum torque and the starting torque are proportional to the square of the supply voltage for any given motor.

Calculated Curves

Motor starting voltage regulation seems to fall most easily into three classes. The first is when the motor takes such a long time to start that steady conditions may be assumed; the second is when the motor starts so quickly that generator transients can not be neglected; and the third is when a regulator acts to increase the alternator excitation immediately after the motor is thrown on. In this last case, the motor may start up quickly, but if the exciter builds up at all rapidly, the minimum voltage will have been reached before the motor starting impedance is very greatly changed.

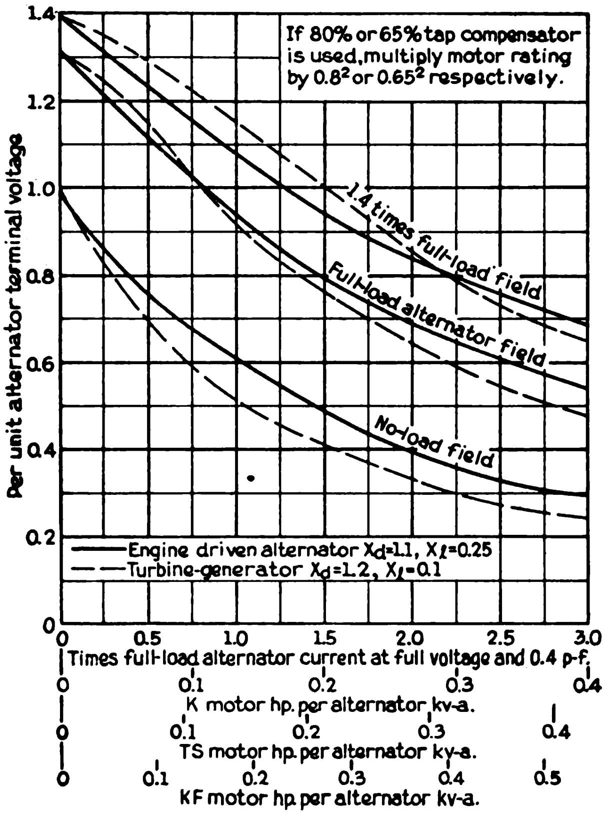

Fig. 5. Calculated Alternator Voltage with Stalled Three-phase Motors

K designates squirrel-cage, normal-torque, normal-starting current
TS designates synchronous, squirrel-cage winding, medium-speed
KF designates squirrel-cage, normal-torque, low-starting current (high reactance)

Analysis of these three cases of motor starting should give a rather complete treatment of the subject, except for the loads that are on the system initially. Loads at high power-factor which decrease with decreasing voltage (*e.g.*, lighting loads) will have relatively little effect unless of rather large value, whereas even a small induction-motor load, where the current quickly increases with drops in voltage, may be a very important factor and must be carefully considered.

It seems most desirable, in view of the complications incident to the many varieties of load possible, to calculate and plot voltage regulation curves with no connected load and to attempt to give such a clear picture of the theory that either a quick estimate of the effect of other loads may be made, or a detailed calculation may be gone through when the exact nature and size of the load are known.

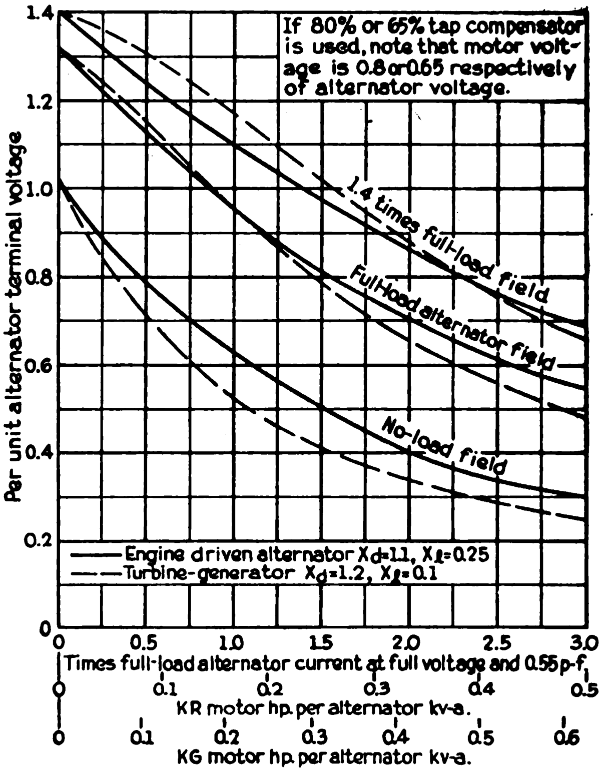

Fig. 6. Calculated Alternator Voltage with Stalled, Three-phase Motors

KR designates squirrel-cage, high-slip, high-resistance rotor
KG designates squirrel-cage, high-torque, low-starting current (high-reactance, high-resistance rotor)

Case 1: If a Motor Starts Slowly

The first two calculated curves (Figs. 5 and 6) represent the voltage regulation when motors take an indefinitely long time to start. The curves are arranged so that the only assumption need be the alternator reactance and saturation, since the voltage is plotted in terms of a definite load current and power-factor. Below the load-current scale is plotted the size of induction motor which on the average will give the current indicated, but it is not necessary to use the motor size scales if the actual starting current is known. Curves are plotted for 0.4 p-f. at starting and also 0.55 p-f. since one or the other will fit fairly accurately the average motor.

One rather surprising conclusion is that the final voltage depends almost entirely upon the amount of current drawn and very little upon its power-factor.

The high average values of alternator reactances chosen are 1.1 and 1.2 for the synchronous reactances of engine-driven and turbine-driven machines respectively, and 0.25 and 0.10 for their respective leakage reactances. The average saturation curves used are given in Fig. 3. A very interesting and useful table of average reactances is given in a recent article.(4)

If a compensator is used, decrease the motor horsepower or current by the square of the ratio of transformation, read the alternator terminal voltage from the graph and decrease this by the ratio of transformation if the voltage at the motor is desired.

The approximate power-factor of a motor when starting can be estimated very handily by a short formula in per unit terms.

$$\text{Starting p-f.} = \frac{\dfrac{\text{P-f.}\times\text{eff.}}{1-\text{full-load slip}}\,(\text{starting torque}+\text{pri. } i^2r)}{\text{Starting current}}$$

Power-factor, efficiency, and slip are all full-load values. This needs hardly any other proof than pointing out that starting torque on a kw. base is in per unit terms the secondary i^2r, and that full-voltage starting current is starting kv-a. (with unit voltage). A good value for primary resistance is 0.025.

Let us give an example of the simplicity of calculation when a motor takes an indefinitely long time to start:

Alternator—engine-driven, as before, 219 kv-a., 240 volts
Motor—50 hp., 240 volts; full-load power-factor—0.9
Full-load current—120 amp.; full-load efficiency—0.91
Starting current—720 amp.; full-load slip—0.04
Starting torque—1.7 times rated torque
Starting power-factor =

$$\frac{0.9\times0.91}{0.96}\times\frac{(1.7+6^2\times0.025)}{6}=0.853\times0.433=0.37$$

Unit current on the alternator base:

$$\frac{219{,}000}{\sqrt{3}\times240}=527\text{ amp.}$$

Per unit motor starting current on the alternator unit base is

$$\frac{720}{527}=1.365$$

Represent the motor by an impedance which gives this current and 0.37 p-f. at unit voltage.

$$z_M=0.271+j\,0.681=0.733\text{ scalar value}$$

It is at this point that other connected loads may be included, by adding motor current and load current vectorially. Note that since the final voltage is going to be different from rated voltage, the current drawn by already connected load must be estimated at the final voltage; some idea of the latter can be obtained from the curves given here. If the already connected load consists of lights or a fixed impedance, it and the impedance chosen for the motor can be combined in parallel.

Impedance behind leakage reactance:

$$0.271+j\,0.681+j\,0.25=0.97\text{ scalar value}$$

Impedance behind synchronous reactance:

$$0.271+j\,0.681+j\,1.1=1.8\text{ scalar value}$$

Let us say that we desire 80 per cent terminal voltage and find the excitation required. If an excitation is assumed first, it is necessary to use trial and error to find the resulting terminal voltage.

With 0.8 motor voltage:

$$e_d=0.8\times\frac{1.8}{0.733}=1.96$$

$$e_f=0.8\times\frac{0.97}{0.733}=1.06$$

The excess for saturation from Fig. 3, given by this value of e_f, is $1.40-1.06=0.34$.

$$1.96+0.34=2.3$$

Full-load excitation we have figured to be 2.45 times the no-load unsaturated field amperes and hence we need $\frac{2.3}{2.45}=0.94$ times rated full-load field current.

This illustrates the complete calculation for one set of conditions if the motor is slow in starting.

Case 2: If a Motor Starts Quickly

The case of a motor that starts before the stored energy of the alternator field has been dissipated will be considered next.

The solution considers voltage, currents, torques, and speeds *step by step*. Calculations have been made and curves plotted (Fig. 7) for normal-torque, normal-current motors, and motors having high starting torque and high rotor resistance, both starting up without load, the rate of speed increase being limited only by the moment of inertia of the rotors. This will give the greatest difference possible between quick starting and indefinitely long starting, and the same general method can be applied to any motor with any load when the motor torque characteristics, the total moment of inertia, and the load torque characteristics are known.

A step-by-step calculation will be gone through as was done for a point on the graph. The average moment of inertia will be assumed as that which requires full-load torque to accelerate the motor to full speed in one second. This is an average value for squirrel-cage induction motors without load and is quite representative for medium-speed ratings.

For normal-torque, normal-current motors, and motors with high starting torque and high rotor resistance, it is possible to choose a simple equivalent circuit as explained previously for estimating torque and impedance up to within a few per cent of synchronous speed. For high-reactance, double squirrel-cage motors, it may be necessary to derive from representative torque and current curves point-to-point values of impedance.

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(4) "System Stability as a Design Problem," by R. H. Park and E. H. Bancker, *Trans. of the A.I.E.E.*, January, 1929, pp. 170-194.

Alternator—219 kv-a., 240 volts; engine-driven.

Motor—*K*, 50-hp., 240 volts, as before.

Let $r_1 = 0.025 \times 0.853 = 0.0213$ on its own kv-a. base (See the calculation of starting power-factor.)

$$r_2 = \frac{0.271 \times 120}{527} - 0.0213 = 0.0404$$

$$x = \frac{0.681 \times 120}{527} = 0.155$$

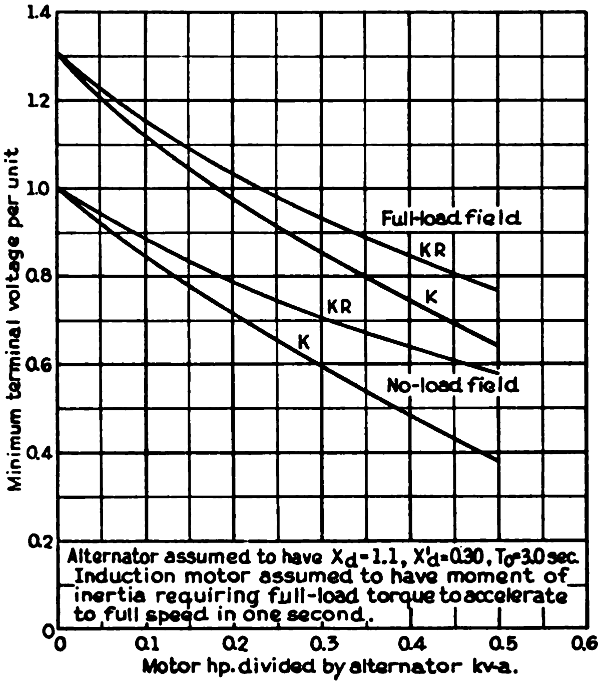

Fig. 7. Calculated Minimum Voltage of Engine-driven Alternator with Induction Motors Thrown on and Perfectly Free to Start

K designates squirrel-cage, normal-torque, normal-starting current
KR designates squirrel-cage, high-slip, high-resistance rotor

We have determined these from the assumption of 0.025 as a likely value for r_1, and the values of 1.7 times normal as the starting torque and 6.0 times normal as the starting current obtained from motor data. (See Case *1*.)

We may now check the value of r_2 by calculating the starting torque, knowing that it is $i^2 r_2$ modified by the factor 0.853 to change from a kv-a. to a kw. base.

$$\text{Full-voltage starting torque} = \frac{6^2 \times 0.0404}{0.853} = 1.7$$

As explained before, we will use for the transient reactance of the alternator a slightly larger value than leakage reactance, say 0.30, leaving the synchronous reactance the same, 1.1. Sub-transient reactances [3] are neglected.

One other constant of the alternator not yet mentioned, is the time constant, a factor inversely proportional to the rate at which the transient begins to die away. This time constant will be assumed on the open-circuit basis as three seconds and it must be noted that it is not independent of the impedance across the generator terminals. The range of open-circuit time constant values is usually given as from two to six seconds, these values being as yet largely empirical. In general, a larger alternator has a larger time constant.

An approximate equation to modify the open-circuit time constant for load impedance is

$$T_0' = T_0 \times \frac{\text{Impedance behind transient reactance}}{\text{Impedance behind synchronous reactance}}$$

The constants of the motor must at this point be changed to the alternator unit base. Rated alternator current is 527 amp. and rated motor current is 120 amp.

$$r_1' = 0.0213 \times \frac{527}{120} = 0.0935$$

$$r_2' = 0.0404 \times \frac{527}{120} = 0.1775$$

$$x' = j\,0.155 \times \frac{527}{120} = j\,0.681$$

$$z_M' = 0.0935 + 0.1775 + j\,0.681 = 0.733, \text{ scalar value}$$

$$T_0' = 3 \times \frac{[0.0935 + 0.1775 + j\,0.681 + j\,0.30]}{[0.0935 + 0.1775 + j\,0.681 + j\,1.1]}$$

$$= 3 \times \frac{1.02}{1.80} = 1.7 \text{ sec.}$$

Assume that the motor is thrown on when rated no-load voltage is on the alternator. The voltage behind the transient reactance will be 1.0, the same of course as for e_t and e_d. Ignoring d-c. transients and a-c. sub-transients, which die away very rapidly, the transient a-c. line current at any instant is equal in per unit terms to the "flux linkages behind the transient reactance" divided by the transient reactance and external impedance in series; voltage and flux linkages can be synonymous in per unit terms if constant speed is assumed.

The voltage at the motor terminals at the first instant, since the same current is flowing in all parts, will be the ratio of the motor impedance to the "impedance behind the transient reactance." It is as if the vector diagram were suddenly opened out with the flux linkages or "voltage behind transient reactance" as a fixed point.

$$e_t = 1.0 \times \frac{0.733}{1.02} = 0.72 \text{ for the first instant.}$$

If this is so, then the voltage behind the synchronous reactance at the initial instant is given by

$$e_d = 0.72 \times \frac{1.80}{0.733} = 1.77, \text{ transient.}$$

This means that in order to keep the voltage behind the leakage reactance the same (constant-linkage theorem), the field current must jump to 1.77; saturation would even add a little to this.

However, the field current can not remain at this high value since there is not the exciter voltage to sustain it, and it must die away—we assume that it is determined by a simple exponential term having the foregoing time constant.

We will further assume no saturation and say that the exciter can sustain 1.0 field current and that the 0.77 must be multiplied by the exponential, to make it disappear, so that

$$e_d = 1.00 + 0.77\,\epsilon^{-t/1.7}$$

This, then, is the voltage at any time across the synchronous reactance and the motor impedance in series. The torque of the motor is simply $\frac{i^2 r_2'}{s}$, where r_2' is 0.1775 on the alternator base, but it must be multiplied by factors to change it from the alternator kv-a. base to the motor kw. base.

Start

$$\frac{i^2 r_2'}{s} = \left(\frac{1.77}{1.80}\right)^2 \times \frac{0.1775}{1} = 0.172$$

$$\text{Starting torque} = 0.172 \times \frac{527}{120} \times \frac{0.96}{0.91 \times 0.9} = 0.885$$

To be absolutely accurate, we should use the mean current and mean rotor resistance during any interval, but here the discrepancies cancel each other in part since the resistance is increasing and the current decreasing, and the percentage change is always small in any event.

Let us choose $\frac{1}{10}$-sec. intervals for our calculations. We have stated that the average value of moment of inertia to be assumed for the motor is that requiring full-load torque to accelerate it in one second to full speed. This torque therefore changes the speed in $\frac{1}{10}$ sec. to

$$0.1 \times 0.885 = 0.0885$$

Let us check the motor terminal voltage at the start by another method:

$$e_t = iz_M = \frac{1.77}{1.80} \times 0.733 = 0.72$$

Second Interval

$$e_d' = 1.00 + 0.77\,\epsilon^{-\frac{0.1}{1.7}} = 1.725$$

$$z_M' = 0.0935 + \frac{0.1775}{1-0.0885} + j\,0.681 = 0.74, \text{ scalar}$$

$$z_d' = 0.288 + j\,0.681 + j\,1.1 = 1.805$$

$$\text{Motor torque} = \left(\frac{1.725}{1.805}\right)^2 \times \frac{0.1775}{1-0.0885} \times \frac{4.39}{0.853} = 0.915$$

This will produce a change in speed of 0.0915 in $\frac{1}{10}$ sec.

New speed is $0.0915 + 0.0885 = 0.18$

$$e_t' = \left(\frac{1.725}{1.805}\right) \times 0.74 = 0.707 \text{ at start of second interval}$$

Third Interval

$$e_d'' = 1.00 + 0.77\,\epsilon^{-\frac{0.2}{1.7}} = 1.685$$

$$z_M'' = 0.0935 + \frac{0.1775}{1-0.18} + j\,0.681 = 0.748$$

$$z_d'' = 0.310 + j\,0.681 + j\,1.1 = 1.81$$

$$e_t'' = \frac{1.685}{1.81} \times 0.748 = 0.696 \text{ at start of third interval}$$

And we could proceed, finding torques, speeds, etc., but the terminal voltage is not going much lower for this particular case, since the motor impedance is becoming larger at a sharply increasing rate.

The assumption of a simple single-circuit to represent motors with normal torque and normal current, or motors with high starting torque and high rotor resistance is sufficiently accurate until 80 per cent speed is reached, and if the minimum terminal voltage has not been reached by this time it can be estimated.

Two factors have been omitted which may at times be quite important. The first is saturation. Some of that field current which is used up initially in saturation will eventually, as the voltage falls, be used to full advantage in opposing armature reaction, and too low a voltage would be calculated if it were forgotten that the amount of saturation during sustained voltage dips may be materially reduced; the safe method is to limit the drop to the value calculated for indefinitely long starts (Case *1*). The second factor is alternator speed. It is almost certain that a great part of the discrepancy in our test results described later for this transient case was due to poor speed regulation of the shunt motor driving the alternator. However, a decrease in speed and frequency and hence in impedance may yield much the same torque for a lower voltage, since current may not be greatly affected.

The curves plotted with motors free to turn should be valuable in estimating voltage dips when a motor is loaded, since these curves and those applying when an indefinite time is taken are the limiting cases and a rough interpolation can be made between them.

Case 3: With a Regulator

The third case is that when a regulator acts to short circuit the exciter field rheostat an instant after the motor is thrown on.

The theory of this is the most complicated of the three, but the application is perhaps the easiest, once the constants of exciter, alternator, and motor are known. The simplification to allow solution by a direct formula is due to Mr. Alan Howard, of the Engineering General Department of the General Electric Company, except for a slight rearrangement of form.

For a solution, we assume that the motor starting impedance does not greatly change with speed until the minimum voltage is past, which tends to put our results on the safe side; the form in which the formula will be presented gives the time of the voltage minimum directly, so that a rough estimate is possible, if desired, of the change in motor speed and hence in motor impedance. Curves calculated for this case are given in Fig. 8.

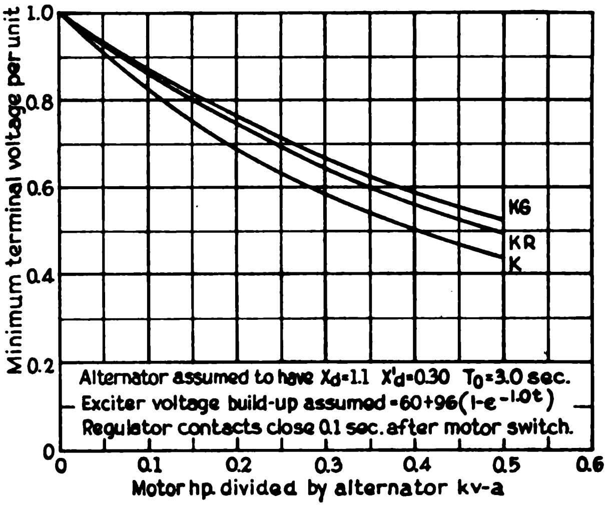

Fig. 8. Calculated Minimum Voltage of Engine-driven Alternators Equipped with Regulators When Induction Motors Assumed Stalled Are Thrown On

Curves for average motors designated *K*, *KR*, and *KG*. (See Figs. 5, 6, and 7)

The following constants are necessary for solution:

(1). Motor starting current and power factor, to fix the motor starting impedance.

(2). Alternator transient and synchronous reactance.

(3). Alternator open-circuit time constant.

(4). Time when regulator contacts close ($\frac{1}{10}$ sec. is a good maximum estimate).

(5). Exciter voltage build-up, including "ceiling" voltage and rate of rise.

This last, the exciter voltage build-up, will probably be the hardest to establish. Results of work in this regard are given in an article previously published, (5) which is believed to be the best reference available. These results, however, are average values from typical machines, hence possibly not suitable for particular cases.

Exciter voltage build-up with separate excitation of the exciter field from a constant voltage source is purely exponential of the form $(1-\epsilon^{-bt})$, except for saturation, but voltage build-up with self-excitation may show a double exponential curve with a very marked inflection point. The first part of such a curve might be represented by $(\epsilon^{ct}-1)$, and the last part by $(1-\epsilon^{-bt})$ and either section of the curve alone could be handled easily, but not both at once. In case the voltage dip takes such a long time that the major part of a "self-excited" curve must be considered, some equivalent single exponential curve must be assumed.

The formula for minimum voltage when a motor is thrown on an alternator equipped with a regulator is:

$$e_m = Q_d\,[1+E_c\,(1-\epsilon^{-b\tau})]$$

This equation for voltage holds only for the instant τ of minimum voltage.

With fair approximation

$$\tau = \frac{(Q_f - Q_d)\;(1-at_r)}{b\,E_c\,Q_d}$$

but for greater accuracy, we may use the formula

$$\tau' = \tau + \frac{b-a}{2}\,\tau^2$$

e_m = Minimum terminal voltage

Q_d = Ratio of motor impedance to impedance behind synchronous reactance

Q_f = Ratio of motor impedance to impedance behind transient reactance

E_c = Maximum or ceiling exciter voltage less exciter voltage at time of connecting motor

b = Exponent of exciter build-up when of form $(1-\epsilon^{-bt})$

a = Exponent of alternator field build-up which is reciprocal of alternator time constant corrected for motor impedance, $= 1/T_0'$

t_r = Time from closing of motor switch to closing of regulator contacts, $\frac{1}{10}$ second being a good maximum value

τ = Time of minimum terminal voltage measured from time when regulator contacts close

In the appendix will be given the slightly changed form of the equation when the exciter voltage build-up is assumed to be of the form $(\epsilon^{ct}-1)$.

Let us give a sample calculation to illustrate the method. We will use the same motor and alternator that were used for the other cases and will assume that the exciter has an equivalent build-up

$$E = 1+1.6\,(1-\epsilon^{-1.0\,t})$$

$$E_c = 1.6, \quad b = 1.0$$

We have arrived at this by assuming an actual voltage

$$E = 60+96\,(1-\epsilon^{-1.0\,t})$$

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(5) "Rates of Voltage Build-up Obtainable with Standard Exciters," by R. W. Washburn, GENERAL ELECTRIC REVIEW, July, 1928, pp. 342-346.

which means 60 exciter volts with no load on the alternator, and a final voltage of 156 volts, with an initial rate of rise

$$\frac{dE}{dt}=96 \text{ volts/sec. at } t=0$$

This agrees fairly well with previous analyses(5) and might represent an average equivalent build-up for exciters with engine-driven alternators, although there is more variation in this than in the other constants we are using and a check should be made for any particular case.

$$Q_d=\frac{[0.271+j\,0.681]}{[0.271+j\,0.681+j\,1.1]}=\frac{0.733}{1.8}=0.407$$

$$Q_f=\frac{[0.271+j\,0.681]}{[0.271+j\,0.681+j\,0.30]}=\frac{0.733}{1.02}=0.72$$

$$a=\frac{1}{T_0'}=\frac{1}{3}\times\frac{1.8}{1.02}=0.59$$

$$\tau=\frac{(0.720-0.407)\ (1-0.59\times 0.1)}{1.0\times 1.6\times 0.407}=0.452$$

$$\tau'=0.452+\frac{(1.0-0.59)}{2}\times 0.452^2=0.494$$

time of minimum voltage after regulator contacts close

$$e_m=0.407\ [1+1.6\ (1-\epsilon^{-1.0\times 0.494})]=0.66$$

minimum terminal voltage

This gives quite conservative results because of neglecting the effect of the motor's starting considered in detail under Case *2*.

The foregoing represents a complete calculation when an alternator is equipped with a regulator. The method is accurate except for the decreasing saturation of the motor with decreasing voltage and for the fact that we have represented the voltage build-up curve by a simple exponential term.

Empirical Rules

A set of empirical rules for the maximum size of centrifugal-pump motor (applicable also to other similar types of drives) to be started from a given alternator has been in use for some time by M. H. Goldhammer of the New York Office of the General Electric Co., who applied them in a slightly different form from that given here..The viewpoint seems to be that of the maximum allowable voltage disturbance on other parts of the system, and not of merely being able to get a motor up to speed. It should be noted in this connection that a compensator is almost certain to be more of a hindrance than a help in getting a single motor started from a torque standpoint; the great advantage is in holding up line voltage for other motors or lights.

The maximum size of three-phase induction-type centrifugal-pump motors to be started from an alternator, applying full field, is, according to good practice:

(1). For wound-rotor motors using secondary resistance, 0.8 hp. per kv-a.

(2). For low-starting current squirrel-cage motors (*KF*), using a compensator, 0.5 hp. per kv-a.

(3). For plain squirrel-cage motors (*K*) using a compensator, 0.4 hp. per kv-a.

(4). For motors the same as (2), but thrown directly on, 0.25 hp. per kv-a.

(5). For motors the same as (3), but thrown directly on, 0.2 hp. per kv-a.

Tests

In order to confirm the theoretical calculations outlined in this article, three 4-pole 3-phase 1800-r.p.m. 440-volt squirrel-cage induction motors, rated 50 hp., 100 hp., and 150 hp. were tested as described under Cases *1*, *2*, and *3*. The alternator used was rated 6 poles, 375 kv-a., 1200 r.p.m., 440 volts, and was driven by a d-c. shunt motor.

In Fig. 9 is given an oscillogram, from the tests of a motor thrown on and free to start. Table I shows agreement of values calculated and obtained by test.

The constants of the alternator used in making these calculations were:

$x_d=0.84$ $x_d'=0.18$
$x_1=0.10$ $T_0=2.07$ sec.

For the exciter, a very old and slow one, the voltage build-up over the range used was given approximately by $1.0+1.25\ (1-\epsilon^{-0.7t})$ where 1.0 represents the exciter voltage (56 volts), to give alternator field current for rated alternator voltage with no load.

The discrepancy between calculated and measured values when the motors were free to start can be explained by the fact that the decrement constants were estimated from oscillograms taken when the motors were blocked and the drop in speed incidental to this was included. When the motors were blocked, the power-factor was low and a small amount of power was drawn from the shunt motor driving the alternator; when the motors started to turn, the power-factor increased rapidly and considerably more power was drawn from the motor-alternator set, slowing it down. This greater drop in speed and frequency would give lower generated voltage.

The "voltage regulator" used was a knife switch short circuiting the exciter field resistance approximately 0.4 sec. after the motors were connected. This time is, of course, much longer than for a real regulator.

For other tests it is interesting to refer to a previously published article(6) giving oscillograms for conditions when two 800-hp. motors were started from a 5385-kv-a. turbine-generator. Some lack of agreement, when the theory outlined in the present article is applied to the transient voltages and currents, is probably traceable to inaccuracy there in scaling values for curves from the oscillograms taken.

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(6) "Quick-Response Generator Voltage Regulator," by E. J. Burnham, J. R. North, and I. R. Dohr, *Trans. of the A.I.E.E.*, July, 1929, pp. 903-911.

APPENDIX

Transient Voltage Dips with a Regulator

The formula given under *Case 3* of motor starting voltage regulation when a motor is started from an alternator equipped with a regulator is developed in the following paragraphs. Mr. Alan Howard is the originator of the analysis given, except for a slight change in the form of the resulting equation.

We assume that the motor does not start until after the minimum point of the voltage dip and that the following are known:

(1). Motor starting impedance

(2). Alternator transient and synchronous reactance

(3). Alternator open circuit time constant

(4). Time when regulator contacts close

(5). Ceiling and rate of rise of exciter voltage.

Let z_d be the scalar value of the impedance behind the synchronous reactance; let z_f be the scalar value of the impedance behind the transient reactance; and let z_M be the scalar value of the motor starting impedance. Then when a motor is suddenly connected with rated no-load a-c. voltage at the alternator terminals, there results a line current which is higher than can be maintained (higher due to trapped flux linkages); and, as previously shown,(2) the current with no regulator may be considered as made up of the sum of a sustained part and a transient part (the subtransient part is neglected).

$$i' = \frac{1}{z_d} + \left(\frac{1}{z_f} - \frac{1}{z_d}\right)\epsilon^{-at'}$$

where a is the reciprocal of the time constant corrected for the connected impedance; or if T_0 is the open-circuit time constant

$$a = \frac{1}{T_0} \times \frac{z_d}{z_f} = \frac{1}{T_0'}$$

$$e_t' = i' z_M = \frac{z_M}{z_d} + \left(\frac{z_M}{z_f} - \frac{z_M}{z_d}\right)\epsilon^{-at'}$$

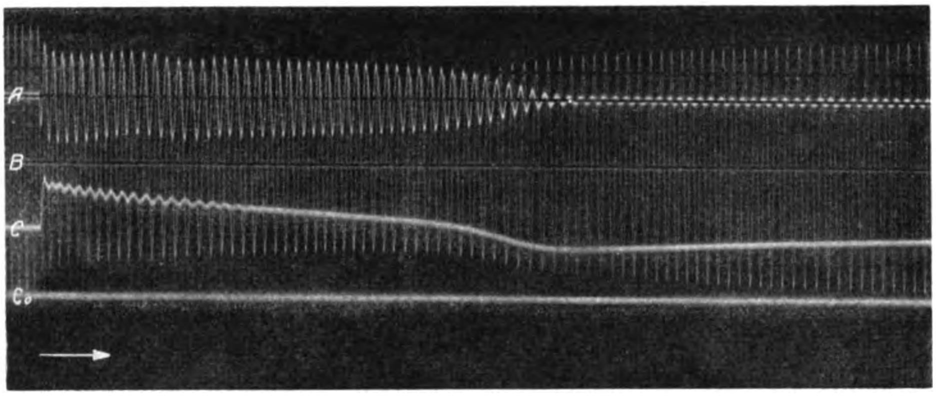

Fig. 9. Oscillogram of Motor Starting with Voltage Regulation
Curve *A*, line current; Curve *B*, line voltage; Curve *C*, alternator field current

TABLE I

PER UNIT MINIMUM VOLTAGES

	50 HORSEPOWER		100 HORSEPOWER		150 HORSEPOWER	
	Calculated	Measured	Calculated	Measured	Calculated	Measured
Case 1: MOTORS BLOCKED—STEADY VALUES ON METER						
No-load alternator field	0.69	0.665	0.465	0.45	0.345	0.34
Full-load alternator field	1.02	0.99	0.73	0.70	0.54	0.51
1-4 full-load alternator field	1.20	....	0.95	0.91	0.72	0.67
Case 2: MOTORS FREE TO START—CONSTANT EXCITER VOLTAGE						
No-load alternator field at start	0.87	0.83	0.65	0.59	0.40	0.39
Time of minimum		0.4 sec.		0.8 sec.		2.0 sec.
Full-load alternator field at start	1.13	1.10	0.94	0.82	0.71	0.64
Time of minimum		0.17 sec.		0.5 sec.		0.7 sec.
Case 3: MOTORS BLOCKED—REGULATOR						
No-load alternator field at start	0.785	0.78	0.58	0.58	0.44	0.47

We will let $Q_d=\frac{z_M}{z_d}$ and $Q_f=\frac{z_M}{z_f}$

$$e_t'=Q_d+(Q_f-Q_d)\,\epsilon^{-at'}$$

This equation is true only as long as the exciter voltage is not changed by the regulator; but by the theory of superposition we may assume that the actual terminal voltage is made up of the sum of this component and another component due to the rise in exciter voltage caused by the regulator.

Assume that the exciter voltage builds up according to the following equation in per unit terms, where the unit base is the voltage necessary to sustain no-load a-c. voltage.

$$E=1+E_c\,(1-\epsilon^{-bt})$$

The operational expression for the transient part of this is

$$\frac{E_c b}{p+b}$$

since this "operating on" the unit function gives $E_c\,(1-\epsilon^{-bt})$. An exposition of operational calculus may be found in recent publications.(7)

An operational expression for the alternator field circuit under transient conditions would similarly be

$$\frac{Q_d a}{p+a}$$

which gives $Q_d\,(1-\epsilon^{-at})$ when a unit voltage is suddenly applied to the alternator field.

When on the alternator field we throw not a unit voltage, but this transient exciter voltage, then for the combined circuit (which, it must be noted, is not linked except by a common electromotive force) we obtain:

$$e_t''=Q_d\,E_c\,\frac{ab}{(p+b)\,(p+a)}\,1$$

The solution for this—from Heaviside's expansion theorem—is

$$e_t''=Q_d\,E_c\left[1+\frac{b\epsilon^{-at}-a\epsilon^{-bt}}{a-b}\right]$$

This is the component due to the regulator action and can by the theory of superposition be added to the other to find the resulting voltage at any time. However, we must point out that the regulator does not act until a time, t_r, after the motor is thrown on and hence the t' of the first component must be replaced by $t+t_r$.

$$e_t=e_t'+e_t''=Q_d+(Q_f-Q_d)\,\epsilon^{-a(t+t_r)}$$
$$+Q_d\,E_c\left[1+\frac{b\epsilon^{-at}-a\epsilon^{-bt}}{a-b}\right]$$

which may be rewritten as

$$e_t=Q_d\,(1+E_c)-\left[\frac{a}{a-b}\,Q_d\,E_c\right]\epsilon^{-bt}$$
$$+\left[\frac{b}{a-b}\,Q_d\,E_c+(Q_f-Q_d)\,\epsilon^{-at_r}\right]\epsilon^{-at}$$

and for a minimum we equate $\frac{de_t}{dt}$ to zero and obtain the condition

$$\left[\frac{b}{a-b}\,Q_d\,E_c+(Q_f-Q_d)\,\epsilon^{-at_r}\right]\epsilon^{-at}=\frac{b}{a-b}\,Q_d\,E_c\,\epsilon^{-bt}$$

We will substitute this condition in the equation for e_t, writing τ for t to indicate the time of the minimum.

$$e_m=Q_d\left[1+E_c\,(1-\epsilon^{-b\tau})\right]$$

Solving the equation giving the minimum condition for τ we obtain

$$\tau=\frac{1}{a-b}\log_e\left[1+\frac{a-b}{b}\,\frac{(Q_f-Q_d)\,\epsilon^{-at_r}}{Q_d\,E_c}\right]$$

and in this we may use two approximations without much loss in accuracy.

$\epsilon^x=1+x$ approximately, when x is small.

$\log_e\,(1+y)=y-\frac{y^2}{2}$ approximately, when y is small.

Whence

$$\tau=\frac{(Q_f-Q_d)\,(1-at_r)}{bQ_d\,E_c}-\frac{(a-b)}{2}\left[\frac{(Q_f-Q_d)\,(1-at_r)}{bQ_d\,E_c}\right]^2$$

If the exciter voltage over the range of action used is of the different form $(\epsilon^{ct}-1)$ (we must be careful here to limit the range used, since the value given by this equation goes eventually to infinity) we may derive in a similar manner a little different form of the equation

$$e_m'=Q_d\,[1+E_c\,(\epsilon^{ct}-1)]$$

whence

$$\tau_c=\frac{(Q_f-Q_d)\,(1-at_r)}{c\,E_c\,Q_d}-\frac{(a+c)}{2}\left[\frac{(Q_f-Q_d)\,(1-at_r)}{c\,E_c\,Q_d}\right]^2$$

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(7) "Heaviside's Operational Calculus as Applied to Engineering and Physics," by Dr. E. J. Berg, GENERAL ELECTRIC REVIEW, Dec., 1927 (and following issues). Also published in book form by McGraw-Hill, New York.

The Development of Modern X-ray Generating Apparatus

PART II

By DR. W. D. COOLIDGE
Associate Director Research Laboratory, General Electric Company

IN the early development of high-voltage generating apparatus, the sources of current used to operate the x-ray tube were the induction coil, the static machine, and the high-frequency coil.

A great stride forward was taken by Snook who developed the Lemp Selector into a very satisfactory high-power source of rectified current.

The Self-rectifying X-ray Tube

The hot-cathode radiator-type of tube made possible the very simple type of equipment in which the tube operates directly from the transformer.

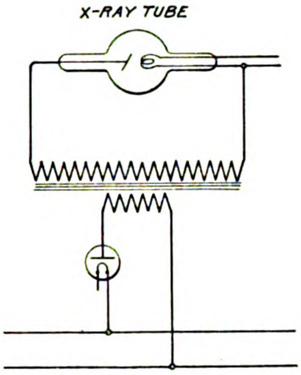

Fig. 19. Diagram of X-ray Generator Circuits with Rectifier in Primary to Reduce Inverse Voltage

The question will be asked as to why a rectifier of any kind should ever be used in series with a self-rectifying x-ray tube for such loads as the latter can by itself safely rectify. There are two reasons for it. In the first place, the focal spot can be made appreciably smaller if the x-ray tube is not required to act as a rectifier. In the second place, an x-ray tube may, by abuse, be brought into such a condition that it will not operate satisfactorily on unrectified current but will still operate in a perfectly satisfactory manner with a rectifier.

In the past it has not seemed practical to operate any half-wave outfit with very high milliamperage owing to the fact that the inverse voltage becomes so high. An invention of Kearsley's(14) has, however, greatly changed this. By the simple introduction of a mercury arc or other rectifier in series with the primary of the x-ray transformer (Fig. 19) he has increased by several fold the allowable output from a given half-wave outfit.

The Kenotron Machine

The Kenotron tube was first described by Dr. Dushman, of our laboratory, in 1915. From the beginning, it has offered a number of advantages over the mechanical rectifier, which are so obvious that one may easily wonder why it did not immediately replace the latter in all x-ray generating equipment. The answer is simply that the mechanical rectifier was at that time a highly developed tool and the Kenotron tube had not been developed to a point where it seemed that it could compete with it in point of reliability. From the standpoint of stability the early form of Kenotron tube would have been entirely satisfactory, but the filament life would have been inadequate, owing to insufficient electrostatic shielding of the filament (Fig. 20). In a later form of Kenotron tube which has been used in many x-ray outfits,

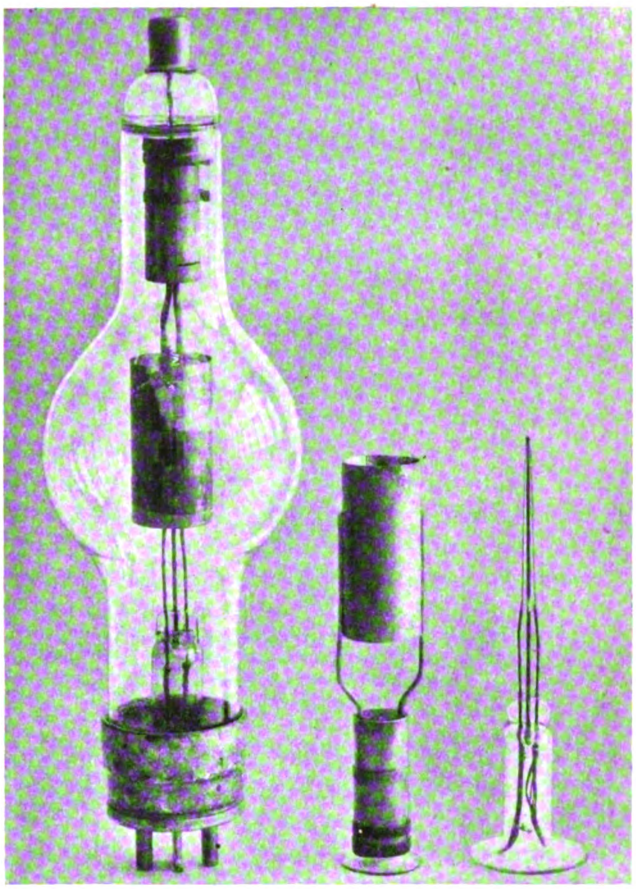

Fig. 20. Early Form of Kenotron Tube and Its Component Parts

there has been a different trouble, due to a variable charging up of the inner surface of the glass (Fig. 21). This has been described by Max Wellauer.(15) As a result of this trouble the voltage drop in the Kenotron tube was a variable quantity, depending on the vacuum. It might be 500 volts or, an instant later, it might be 5000 volts. As with the bridge connection (full-wave rectification) there were two Kenotron tubes in series, this introduced an uncertainty of several thousand volts in the voltage supplied to the x-ray tube and was therefore opposed to the exact duplication of radiographic results. In still later forms the anode is, as at first, made to surround the cathode, thus eliminating the instability.

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(14) General Electric Review, Vol. 33, pp. 572-573 (1930).

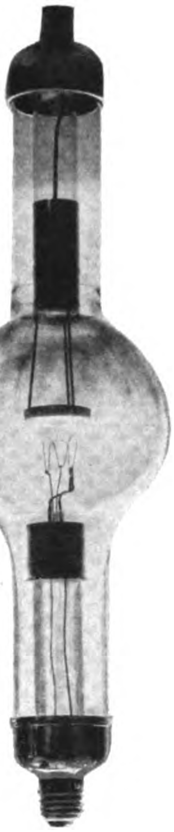

Fig. 21. One of the Forms of Kenotron Tube which Has Been Used as a Substitute for a Mechanical Rectifier in X-ray Generator Circuits

It has been shown that the x-ray output per milliampere is the same from a Kenotron machine as from a properly adjusted mechanical rectifier and higher than from an improperly adjusted one.

There is no valid objection to the idea of a Kenotron machine, and the future of this type of equipment will depend entirely upon the satisfactoriness of the Kenotron tube itself and upon apparatus design features calculated to minimize as much as possible the needless demands made upon the Kenotron tube.

By the use of a multiplicity of Kenotron tubes on multiphase current, or with Kenotron tubes and condensers, voltage fluctuations at the tube terminals may be reduced to any desired extent; *i.e.*, one may approach as closely as he desires to constant-potential continuous current.

The Induction Coil for Very High Voltage

For the production of very high voltage radiation, a type of induction coil has been developed which is relatively cheap and easy to make and very satisfactory (Fig. 22). Its designers started with the idea of using solid dielectric between the primary and secondary, but have found it much better to rely mainly on oil. The container *A* is a Herkolite (paper-resin) tank. The primary *B* is a helical coil wound on an insulating tube that surrounds the core *C*. The secondary *D* consists of thin coils placed one on top of the other with paper rings between. The lower end of the secondary is grounded, and the potential difference between secondary and primary then increases as we come up, reaching its maximum at the top of the secondary. Arc-over would take place from the top of the secondary to the primary at about 600,000 volts were it not for the split aluminum spinning *E*, which electrostatically shields the upper end of the coil and makes it possible to go to about 800,000 volts. At this point, arc-over would take place from the aluminum spinning to the upper end of the core were it not for the spherical shield *F*, which makes it possible to go up to 900,000 volts. The design of this shield is important as it has to be electrically conducting and is located where nearly all of the magnetic flux of the core passes through it. If it were a hollow metal sphere of appreciable thickness, most of the energy delivered to the primary would be wasted in the sphere in eddy currents. The construction indicated has been found satisfactory and consists of a wooden sphere overlaid with narrow strips of sheet aluminum placed as shown, and metallically joined at the top to the upper end of the core.

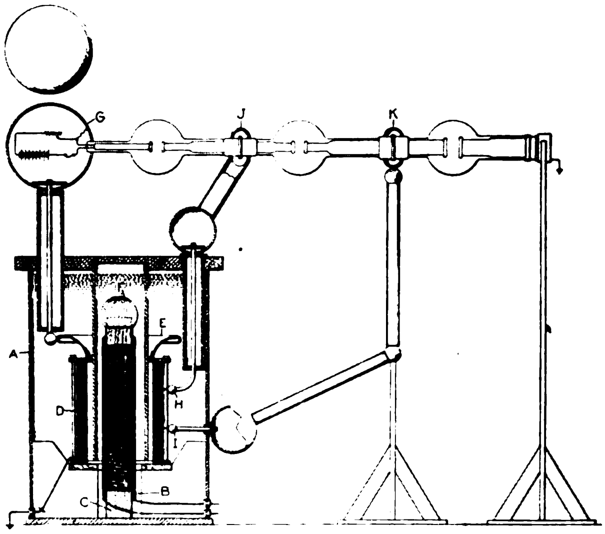

Fig. 22. Diagram of Induction Coil for Supplying 900,000 Volts to Operate a Multi-section X-ray Tube

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(15) *Archiv fur Elektrotechnik*, Vol. 16, pp. 13-27 (1926).

The 900,000-volt lead passes up through an oil bushing to a 20-in. hollow metal sphere *G* which serves as a container for the storage battery used to light the filament and, at the same time, as a terminal of the measuring sphere-gap. To secure other potentials for the intermediate electrodes of a three-section tube, the 600,000 and 300,000-volt taps, *H* and *I*, are brought out to the intermediate sections of the tube, *J* and *K* respectively.

The coil is operated from 1200-volt 60-cycle current, by means of a hydrogen-filled mercury turbine interrupter driven by a synchronous motor. Such an outfit is to be installed shortly, for experimental therapy, at the General Memorial Hospital in New York.

As one end of the secondary is grounded, it will doubtless be possible to operate two such coils in series to produce 1,800,000 volts. It seems, furthermore, as though larger coils could be built in this way for much higher voltages.

It may seem like turning the clock backwards to be working on induction coil developments at this time, and that it would be better to use transformers with Kenotron tubes and condensers. For the medical applications, however, it seems as though very little current would be required at these high voltages; and if this is true, the induction coil seems to be especially suited to the purpose, and for the following reasons: In the first place, there is no need of any auxiliary rectifying device, as the x-ray tube is capable of rectifying its own current. The induction coil gives such an unsymmetrical wave that, even with resistance control, the "useful" voltage will be higher than the "inverse," and, as a result, and without the need of any complications, the sphere gap will indicate the "useful" voltage. Furthermore, owing to the simplicity of the high-tension circuit, the corona loss can be made negligible. The high magnetic leakage, inherent in the straight open core, and the resistance control both tend to greatly diminish the electrical hazard; they also make it unnecessary to use resistances in series with the measuring sphere-gap.

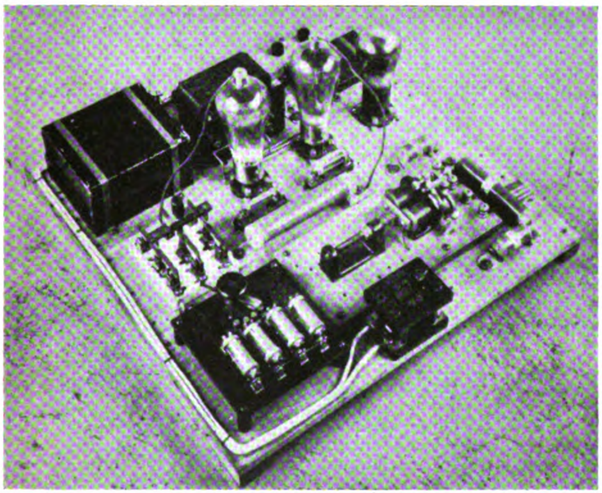

Fig. 23. Kearsley Vacuum-tube Time Switch

Upper left: Condenser
Lower left: Adjustable rheostat
Upper right: Thyratron tubes
Lower right: Relay

Protection from Electric Shock, and the Oil-immersed Type of Equipment

The hot-cathode tube has brought in its train, for radiographic work, auto-transformer control. This has increased the danger from accidental contact with the high-tension circuit. Even with resistance control, however, the danger would still be very great when using high milliamperage. For these reasons more attention must be given to the matter of electrical protection.

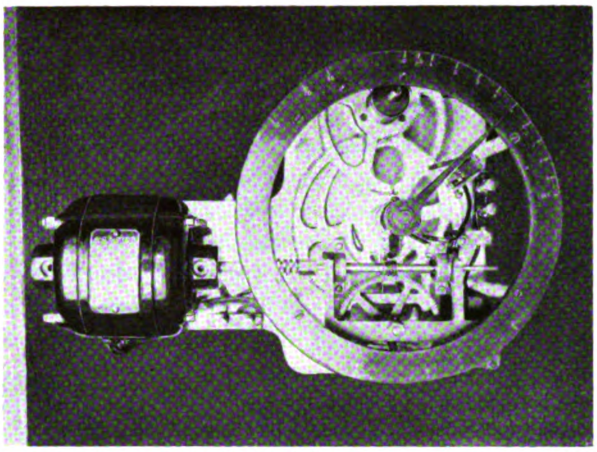

Fig. 24. Kearsley Mechanical Time Switch

For diagnostic work, the outfit in which the x-ray tube and the entire high-tension circuit are immersed in oil in a grounded metal container promises to become the final type of x-ray generating equipment, for the following reasons:

(1). It completely eliminates the electrical hazard.

(2). By permitting a great reduction in the length of the anode arm of the tube, and hence the anode stem, it gives a corresponding increase in the rapidity of heat removal from the anode, thus allowing increased x-ray output in a given time.

(3). It eliminates the effect of altitude and humidity.

(4). It eliminates fire risk in the presence of ether vapor.

(5). It gives mechanical protection to the x-ray tube and insures the mechanical integrity of the entire high-tension circuit.

For mechanical reasons, it is desirable that the weight and bulk of the head of an oil-immersed outfit should be kept as low as possible. If the movable part were too heavy, its inertia would be troublesome, making it too laborious, even in the absence of all friction, to produce the acceleration and deceleration involved in moving it quickly from one position to another in space. These conditions have seemed to favor half-wave operation, and this, because of the "inverse" problem, has limited the capacity of such outfits. Kearsley has recently found, however, as already mentioned, that with half-wave operation, "inverse" can be greatly reduced by the use of a mercury arc or other rectifier in series with the low-voltage primary circuit. In this way a several-fold increase in capacity may be made without increase in size—in fact without any change in the movable member.

Precision Timing in Fast Radiography

Generally speaking, it seems questionable whether very high speed radiographic work has, in the past, been satisfactory. The reason for this is to be found in the fact that with increase in speed there has in general been a decrease in the precision of the work. In other words, it has not been possible to duplicate results as closely. This is partly due to imperfections in the timing device itself, but more especially to the fact that the time taken in actually opening the circuit was so variable, depending on whether it happened that the event was scheduled to take place at zero, or at the peak, or at some intermediate point in the voltage wave.

To get precision timing for high-speed work, it is desirable to make and break the primary circuit at zero on the voltage wave. This result has been accomplished in two ways by Kearsley.⁽¹⁶⁾ One of these is a vacuum-tube time switch, with no moving parts, consisting essentially of a condenser which is first charged to a definite potential and then discharged through an adjustable rheostat. When the condenser voltage has dropped to a certain value, in a time determined by the value of the resistance used, the x-ray circuit is opened through the control of the potential of a grid in a small Thyratron tube. Where a relay is not objectionable, one may be added to the output circuit of the vacuum-tube time switch for special applications (Fig. 23).

Another way is a synchronous-motor-driven time switch (Fig. 24) which is so designed that the exposure may be started on zero and then, through grid control with Thyratron or Pliotron tubes, stopped on zero after the desired number of current impulses. This form of time switch is particularly noteworthy for its high precision, which is obtained through the use of the synchronous motor and a positive gear drive from the motor to the contacts.

The switch is provided with a tapered scale with widely spaced divisions below one second, thus giving equal precision in setting throughout the whole twenty-five-second range. This makes accurate setting easier, and there is much less chance of error than where a double scale and selector switch are employed.

An unusual feature of this switch is that the motor does not operate continuously but starts an instant before the exposure is to be made and stops when the control switch is released. This not only insures quietness of operation but greatly reduces wear, and simplifies lubrication problems.

It has been the purpose of this presentation to emphasize some of the fundamental principles involved, so as to show why x-ray generating apparatus has its present limitations and to indicate in a few cases how the capabilities of the apparatus may be increased in the future.

(*Concluded*)

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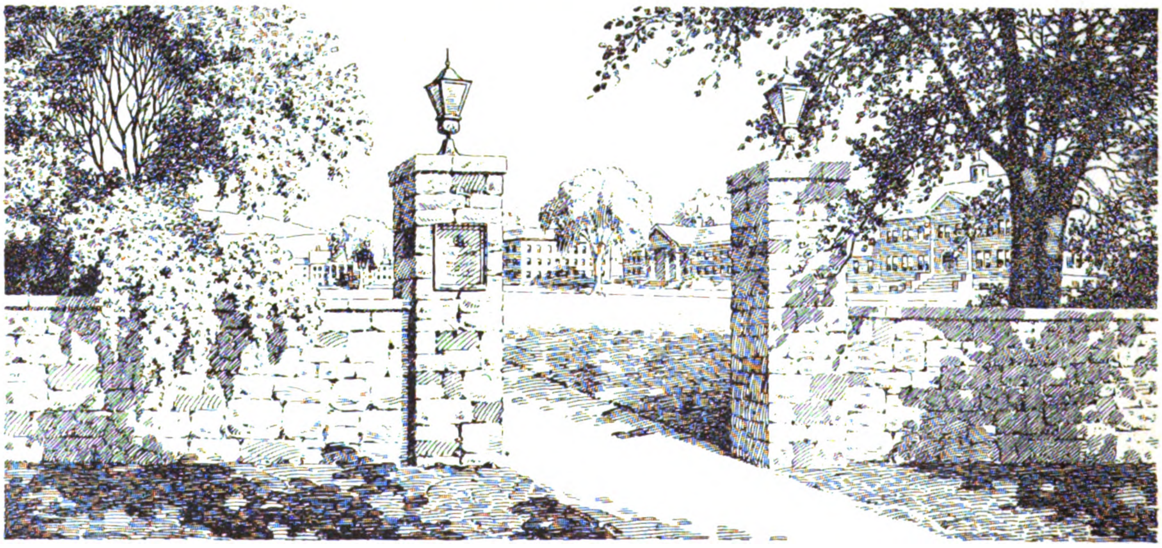
(16) To be published in the General Electric Review.



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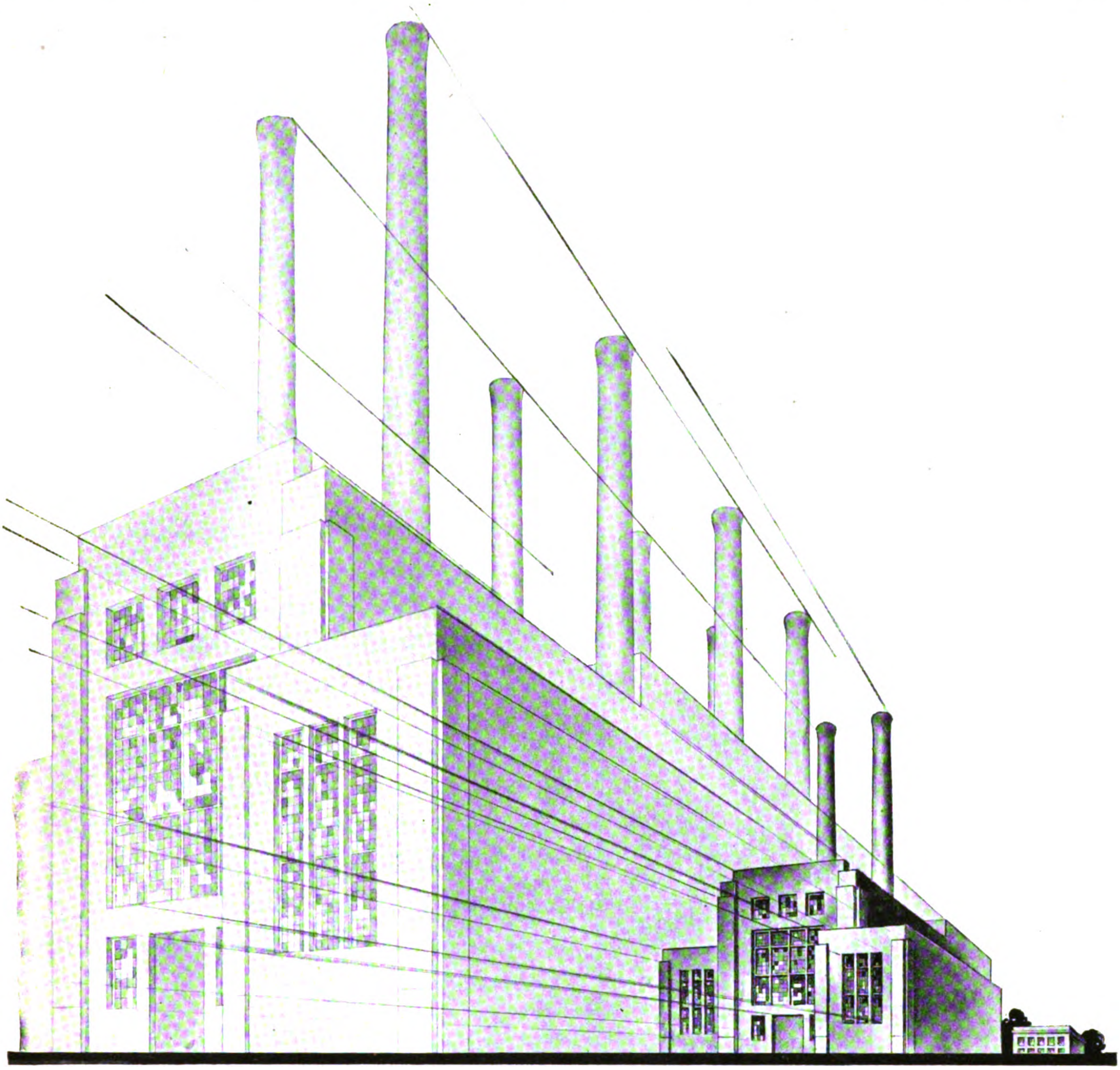

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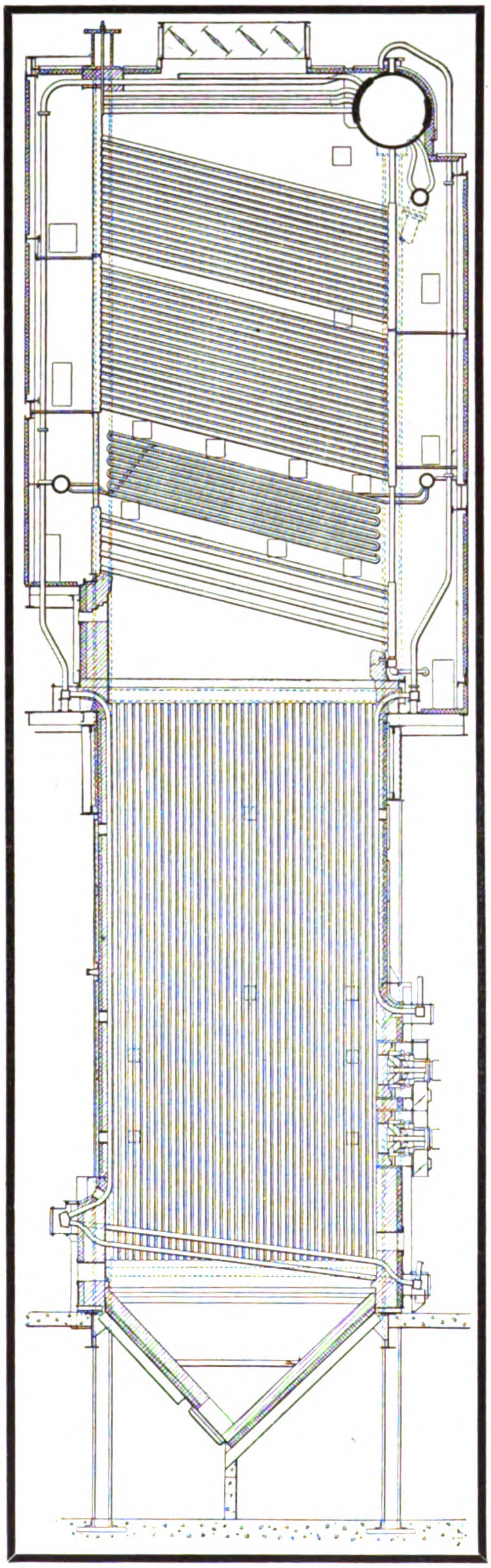

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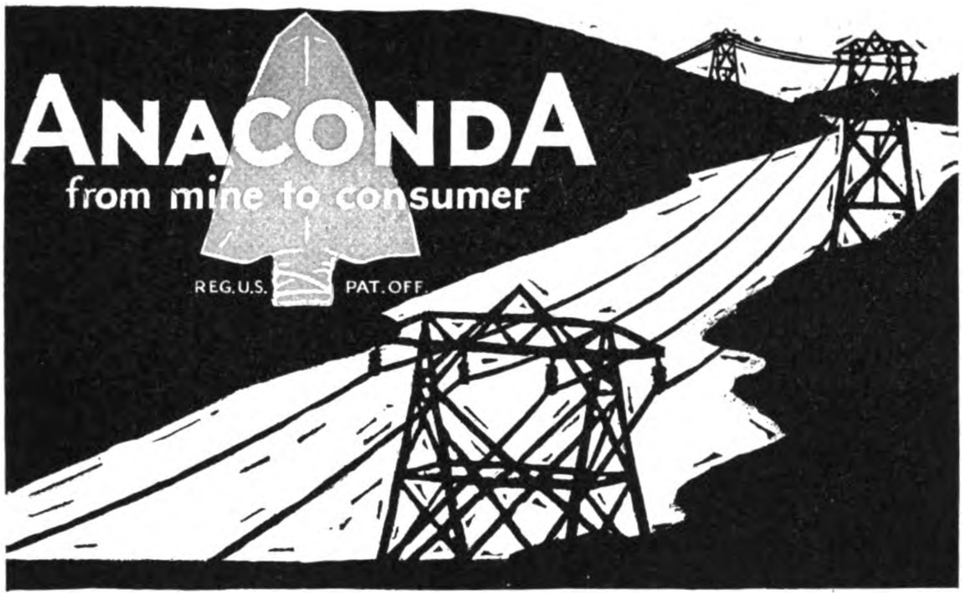

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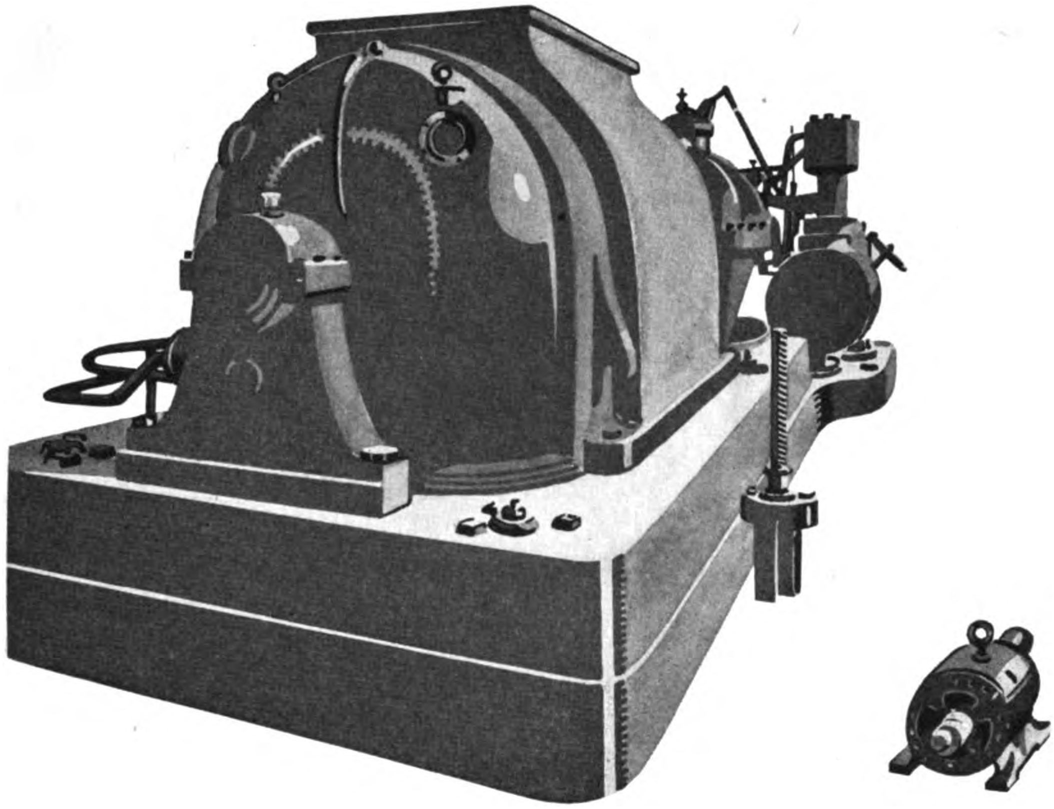

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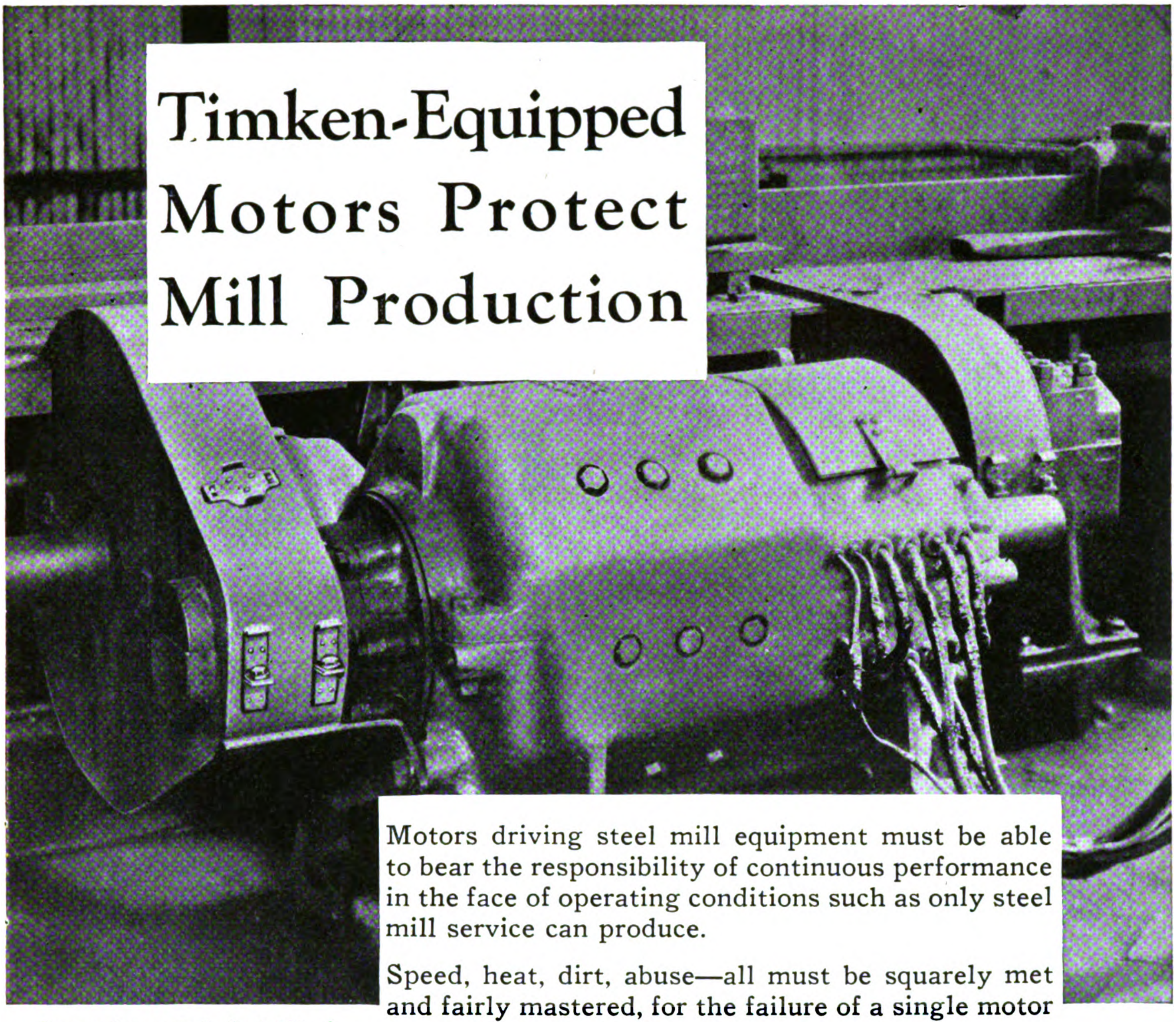

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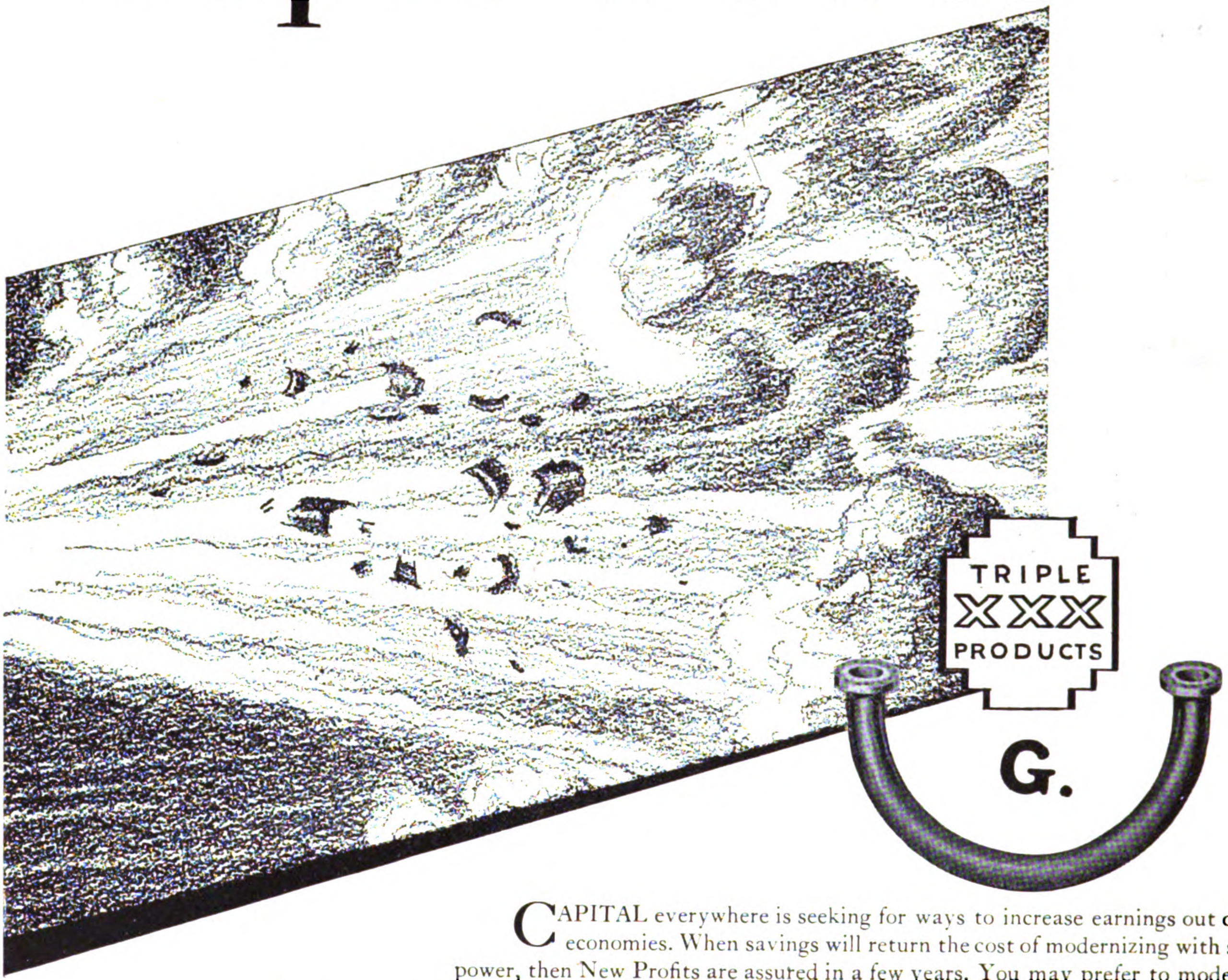

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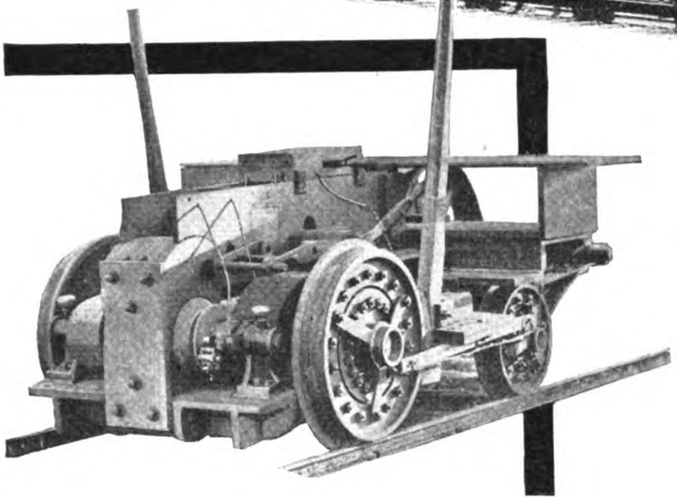

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another fiftieth anniversary

JUST A YEAR AGO tribute was paid to Thomas Edison on the anniversary of his epoch-making invention—the Incandescent Lamp. This year marks another anniversary which the world may not celebrate, but which people interested in electrical progress will remember—that of Edison's invention of the first electric locomotive.

The little machine pictured at the left was built by Edison in 1880 to prove that the application of electricity to traction was practicable. It was operated with a loose belt and idler control. Hand-levers served as brakes. Current was carried by the rails, through the wheel-rims which were insulated from the axles. The motor was equipped with copper-leaf brushes.

For some years progress was slow. Then came carbon brushes which overcame the greatest difficulty—that of commutator wear. National Carbon Brushes played a vital part in the development which followed. Splendid research facilities, backed by years of experience in carbon manufacture, made possible the constant improvement of brushes.

The march of progress since 1880 is revealed in the illustration at the right, showing one of the huge 3000-volt, electric locomotives recently placed in operation to haul the many trains daily passing through the new Cleveland Union Terminal. In electric traction, as in other applications of power to industry, National Pyramid Brushes occupy an undisputed position of leadership.

NATIONAL CARBON COMPANY, INC.

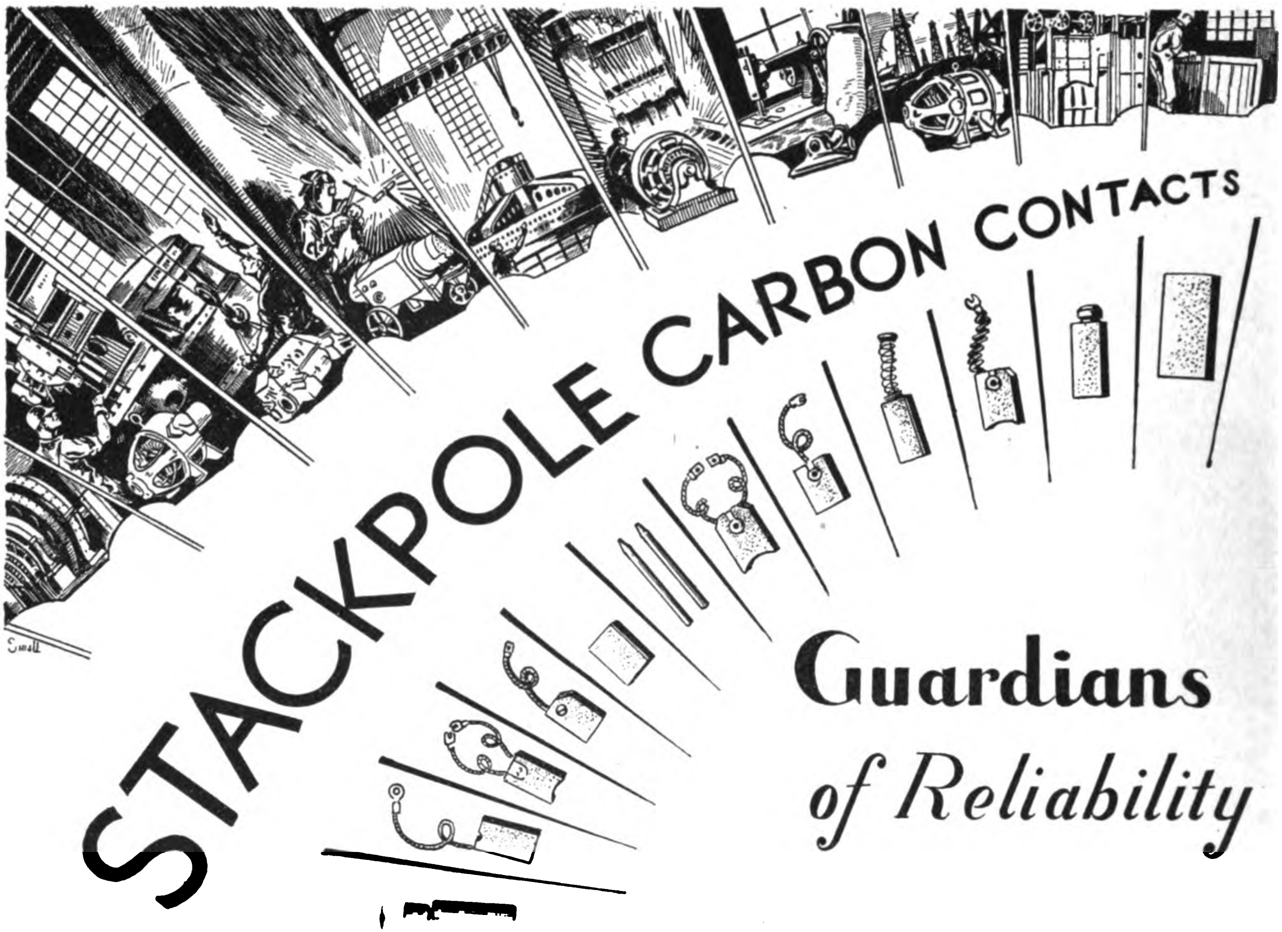
Unit of Union Carbide and Carbon Corporation

SILVER STRAND CABLE TRADE MARK REGISTERED

Carbon Sales Division Cleveland, Ohio

Branch Offices and Factories

New York Pittsburgh Chicago Birmingham San Francisco



Successful Stackpole Brush and Contact Grades

TRACTION—L-30, L-31, B-22
ROTARY CONVERTER
DC end—B-22, M-57
AC end—S-83, 933
DC INDUSTRIAL MOTORS
L-21, L-30, S-11
MINE MOTORS
L-30, S-11
MILL MOTORS
L-30, S-11
SWITCH METAL GRAPHITE CONTACTS
S-81, S-86
SLIP RING INDUCTION MOTORS
S-86, A-10

Stackpole Brushes and Contacts are giving outstanding service on—

ROTATING ELECTRICAL MACHINERY
SWITCHES
CIRCUIT BREAKERS
WELDING MACHINES
ELECTRIC FURNACES
ELECTROLYTIC CELLS
AUTOMOBILE STARTERS
LIGHTING GENERATORS
FRACTIONAL H. P. MOTORS
THERAPEUTIC CARBONS

Let Stackpole Help to Solve Your Contact Problems

Representatives in the following cities: Boston, Chicago, Cleveland, Detroit, Havana, Huntington, Indianapolis, Los Angeles, New York City, Philadelphia, Pittsburgh, Rochester, San Francisco, Seattle and Toledo. *Write for the address of our nearest representative.*

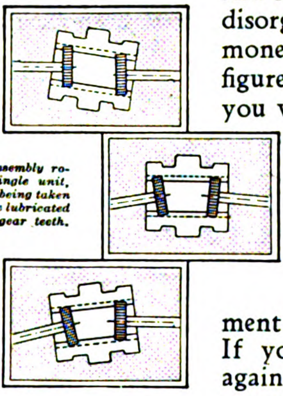
STACKPOLE CARBON COMPANY - ST. MARYS, PA.

FAST'S Self-Aligning COUPLING

"Here's the Answer to this Coupling Problem"

Do you have coupling break-downs resulting from the "fatigue" and failure of flexible members such as bushings, pins, springs, discs and grids?

By eliminating these flexible materials Fast furnished the answer to this baffling coupling problem. The simple mechanical principle has established a new and better coupling practice. Notice the diagrams at the right. Two spur gears are in complete and continuous mesh with the internal gears of a floating sleeve. The sleeve takes a neutral position, the error of misalignment being taken up between the lubricated faces of the gear teeth, and all necessity of flexible materials is eliminated.



The entire assembly rotates as a single unit, misalignment being taken up between the lubricated faces of the gear teeth.

Free From Shut-downs

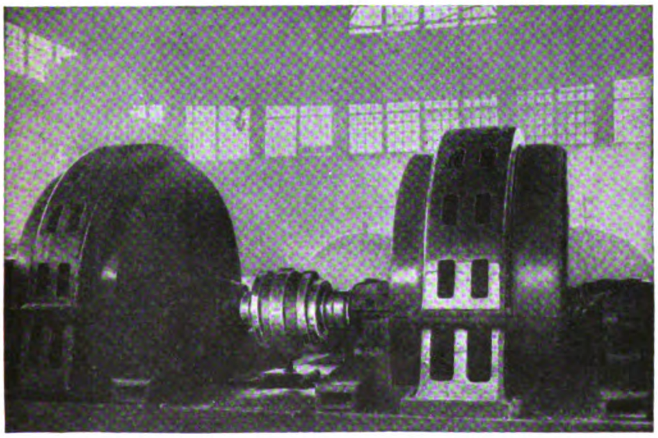
Fast's Self-Aligning Couplings become part of the permanent transmission machinery of your plant. Give them the same care and they will last as long as the connected machines.

With Fast's Couplings your plant is free from production tie-ups formerly due to coupling break-downs. Check back over your records (or in your memory) and see how much delay, lost production and disorganized operation have cost you in both money and efficiency. Then compare this figure with the cost of installing Fast's and you will understand why they are economical.

Standardize on Fast's

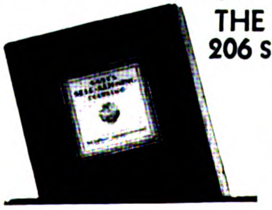
Thousands of plants throughout the country have standardized on Fast's Self-Aligning Couplings on all new equipment and for all replacements. Every installation requirement in your industry is met by Fast's design. If you specify Fast's you protect yourself against coupling break-downs. Any machinery or equipment builder will furnish them.

Mail the coupon to the Bartlett Hayward Company and receive a free copy of the new 10th Anniversary Catalog giving complete details of Fast's Self-Aligning Couplings and their application in your industry.



Cut-out type on 10,000 K.V.A. Frequency Changer, Appalachian Power Co., Switchback, W. Va.

Send for NEW Catalog



THE BARTLETT HAYWARD CO.
206 Scott Street - - Baltimore, Md.

Send me the free bound copy of the new Fast's 10th Anniversary Catalog showing varieties of designs and installations, containing valuable data on coupling installation.

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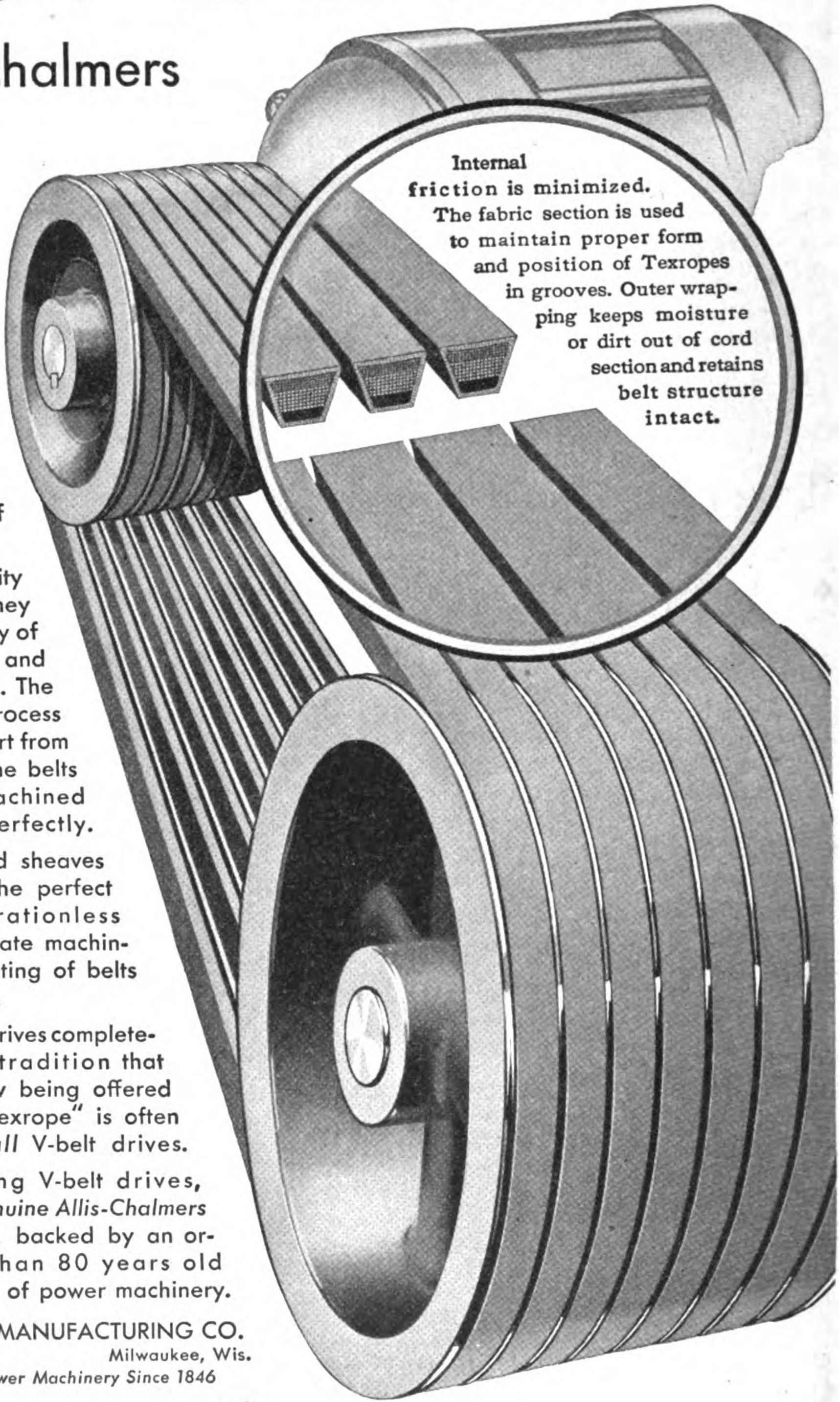
....There is only ONE TEXROPE DRIVE

It is made by Allis-Chalmers

and its use assures perfect performance!



Internal friction is minimized. The fabric section is used to maintain proper form and position of Texropes in grooves. Outer wrapping keeps moisture or dirt out of cord section and retains belt structure intact.

SO attractive are the savings effected with Texrope Drives that over 80,000 have been sold. Wherever correctly applied they have never failed to give complete satisfaction.

In originating and developing this drive that has revolutionized transmission methods, Allis-Chalmers has achieved the perfection that comes only after years of practical experience.

Texrope Belts possess amazing flexibility and long life. The process by which they are made is the result of every facility of The B. F. Goodrich Rubber Company and the vast Allis-Chalmers organization. The belt cores are built by a special process . . . the outer wrapper prevents dirt from working into the cord section. The belts are formed in accurately machined molds. They always seat perfectly.

In the manufacture of grooved sheaves Allis-Chalmers has secured the perfect balance so necessary to vibrationless operation . . . and the accurate machining that assures perfect seating of belts and unusually long service.

So rapidly have Texrope Drives completely smashed transmission tradition that many imitations are now being offered . . . and the word "Texrope" is often used in referring to *all* V-belt drives.

When you are buying V-belt drives, be *sure* to get the *genuine Allis-Chalmers Texrope Drives* . . . backed by an organization more than 80 years old in the manufacture of power machinery.

TEXROPE DRIVES

The Whole Story in 8 Minutes

In 8 minutes you can get the whole story of Texrope Drives from this illustrated book. *Ask for a copy of Bulletin 1228.*

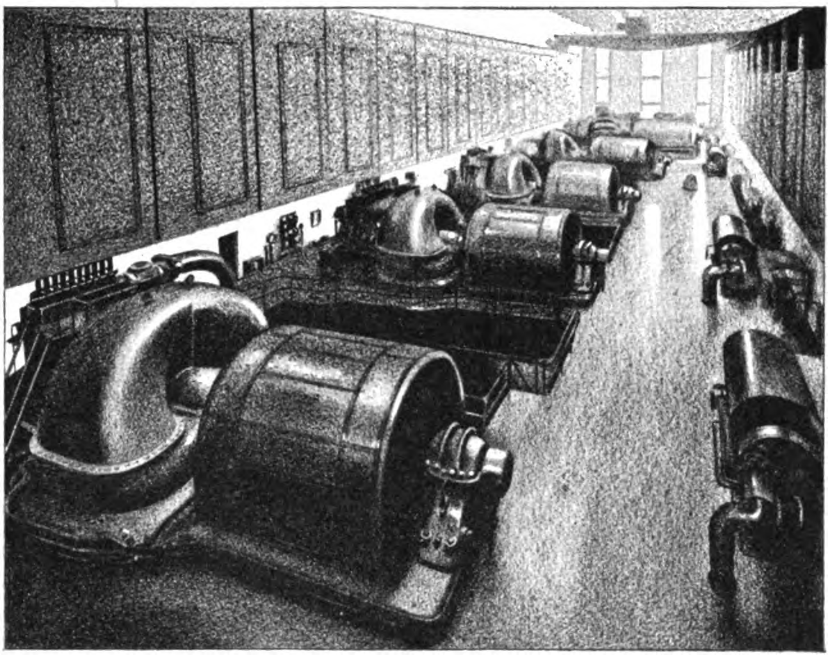
ALLIS-CHALMERS MANUFACTURING CO.
Texrope Division Milwaukee, Wis.
Specialists in Power Machinery Since 1846

ORIGINATED BY ALLIS-CHALMERS

TEXROPE DRIVES

THE DRIVES THAT REVOLUTIONIZED TRANSMISSION PRACTICE • • •

ALLIS CHALMERS TEXROPE DRIVE



The snap of an electric switch now turns on the light for over 70% of America's dwellings. In 1929, 88,000,000,000 kilowatt-hours of electrical energy traveled over 135,000 miles of transmission wires to 24 million domestic, commercial, and industrial customers. Over $788,000,000 was spent during 1929 for new electrical facilities.

As generator after generator has been added to the country's electrical resources, the Vacuum Oil Company has kept pace, with the result that—

More electrical energy is produced by machines★ lubricated with Vacuum Oils than with any other brand of oil in the world.

Improvements are occurring daily in mechanical equipment—many are accompanied by lubrication changes which overturn established methods in the interests of greater efficiency.

Vacuum Oil Company engineers are in constant contact with these changes. They have originated many of them and adapted them to the lubrication of all kinds of machinery, both old and new.

From our 64 years of experience in anticipating the lubrication needs of industry, one of our representatives can bring you a store of useful information, that will enable you to employ the best and most economical developments in lubrication practice. We invite you to get in touch with us.

★ These machines include steam turbines, water turbines, reciprocating steam engines and Diesel engines. The figures on the market are by courtesy of Electrical World.

QUALITY BRINGS LEADERSHIP

GARGOYLE

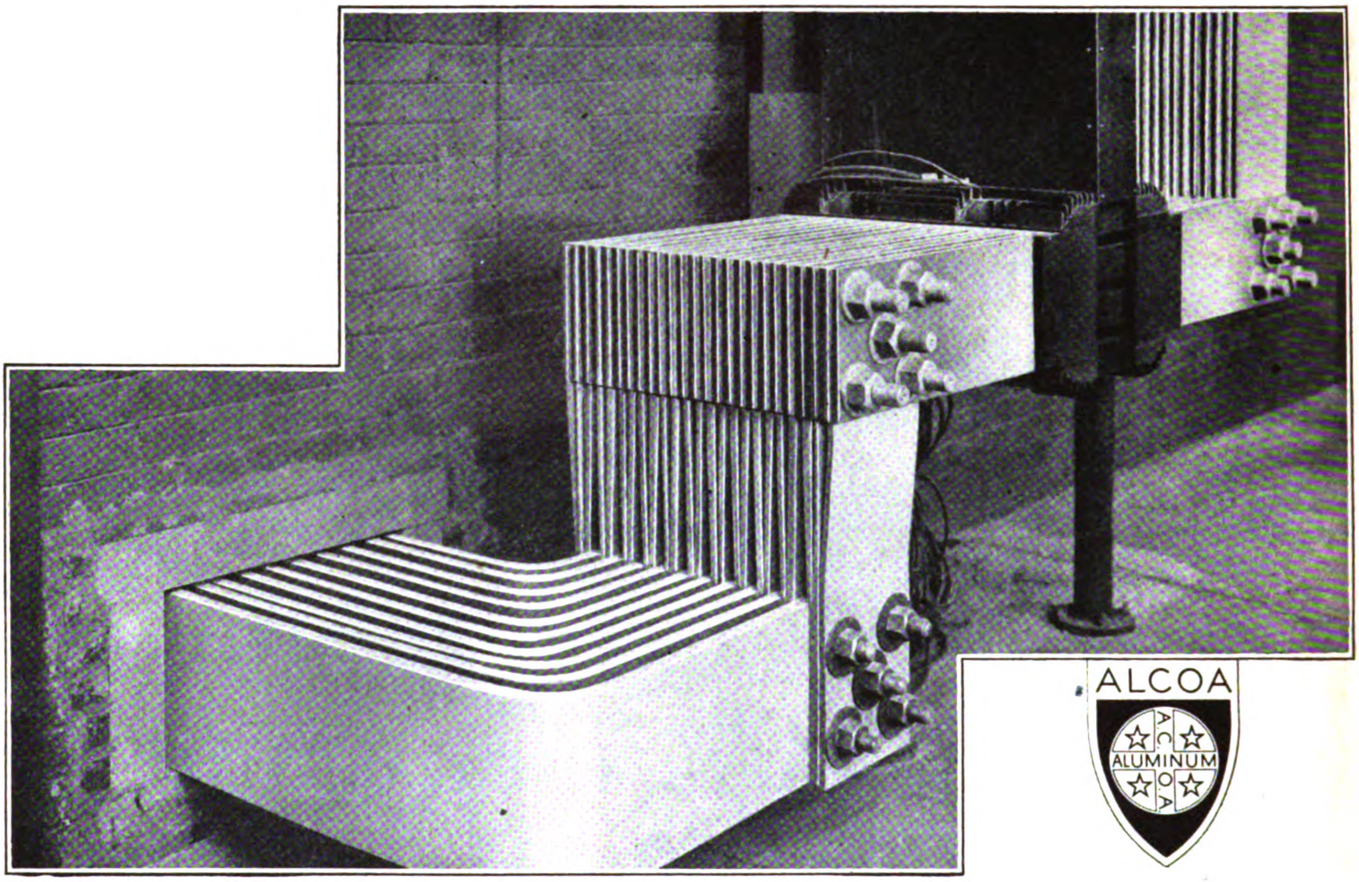
Lubricating Oils

The world's quality oils for plant lubrication

VACUUM OIL COMPANY

Headquarters: 61 Broadway, New York. Branches and distributing warehouses throughout the country

Approximately 90 lbs. of dead-weight per running foot saved on this job by using Alcoa Aluminum Busses



This picture shows Alcoa Aluminum Bus Bars used in connection with a 50,000 ampere direct current meter shunt. The ten large bars entering from the wall are 1″ x 12″. The twenty-four bars connecting with the shunt are ½″ x 10″. All are made of Alcoa Aluminum, at a dead-weight saving of approximately 90 lbs. per running foot.

This big weight saving was made possible because, for the same conductance, the weight of Alcoa Aluminum Bus Bars is only 48% of that of other bars commonly used for busses.

Alcoa Aluminum Bus Bars make possible longer spans and fewer joints. Their light weight calls for the use of lighter supporting structures.

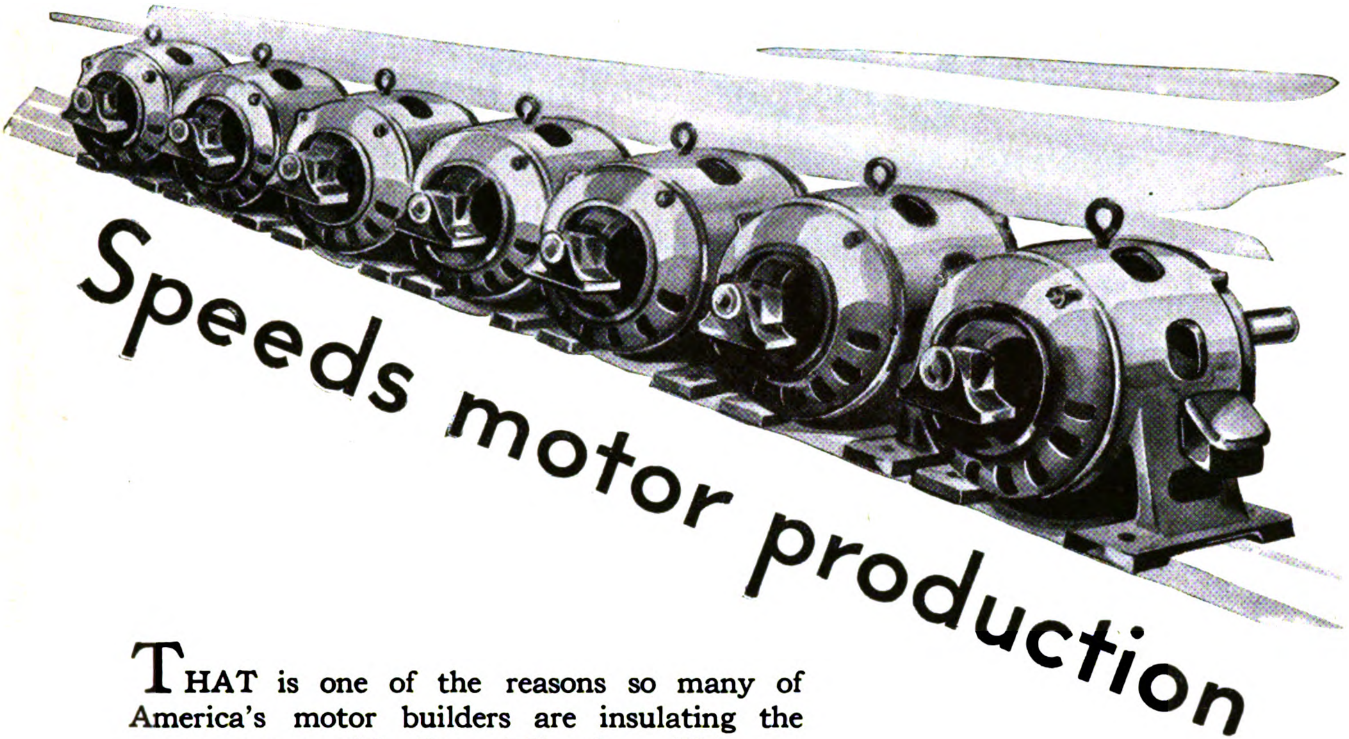
Another unique advantage of Alcoa Aluminum Bus Bars is that, for the same conductance, they have a lower operating temperature than busses made of other metals.

Tables of weights, carrying capacities and other technical data are contained in the booklet, "Aluminum Bus Bars". May we send you a copy? ALUMINUM COMPANY *of* AMERICA; 2457 Oliver Building, PITTSBURGH, PENNSYLVANIA.

BUS BARS MADE OF

ALCOA ALUMINUM

Higher Baking Temperature



THAT is one of the reasons so many of America's motor builders are insulating the commutators with Super-Micanite. This unusual electrical insulation permits of baking temperatures above that which ordinary built-up Mica will withstand. Quicker production is the result.

That's not all. A better commutator is also produced. Super-Micanite has greater electric strength and less surface leakage. It is denser, hence assures more accurate spacing of commutator bars and greater ease in assembly. Even at high temperatures no corrosive decomposition products are formed.

These outstanding advantages have made Super-Micanite the choice of leading motor and generator builders. Many of its varied uses are described in Catalog 87. Write for a copy.

MICA INSULATOR COMPANY
New York: 200 Varick St. Chicago: 542 So. Dearborn St.
Cleveland Pittsburgh Cincinnati Birmingham Seattle
San Francisco Los Angeles Toronto Montreal
***Works:* Schenectady, N. Y. London, England**

PERFECT MICANITE INSULATOR
REG. U.S. PAT. OFF.

Electrical INSULATION

PERFECT EMPIRE INSULATOR
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MICA INSULATION OILED CLOTH INSULATION

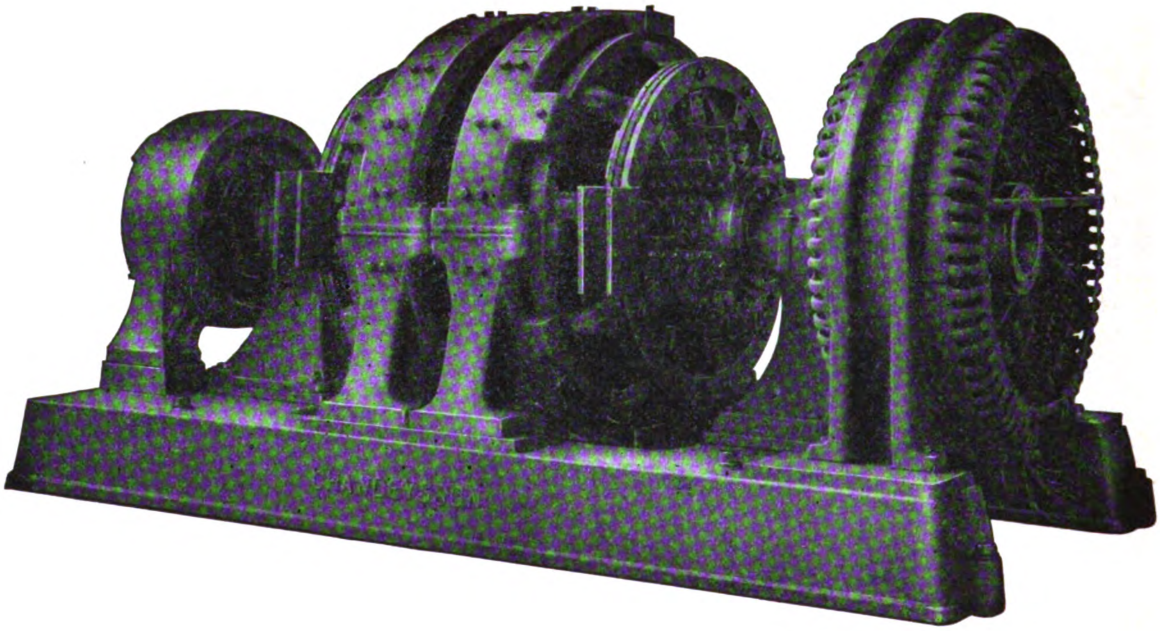
Chandeysson

Generators

25 to 25,000 Amperes

Direct Connected to

General Electric Motors



TWIN GENERATOR TYPE

1 Greater Flexibility
2 Higher Efficiency
3 Floor Economy
4 Lower Cost

Write for Bulletin 114

CHANDEYSSON ELECTRIC CO., St. Louis, U. S. A.

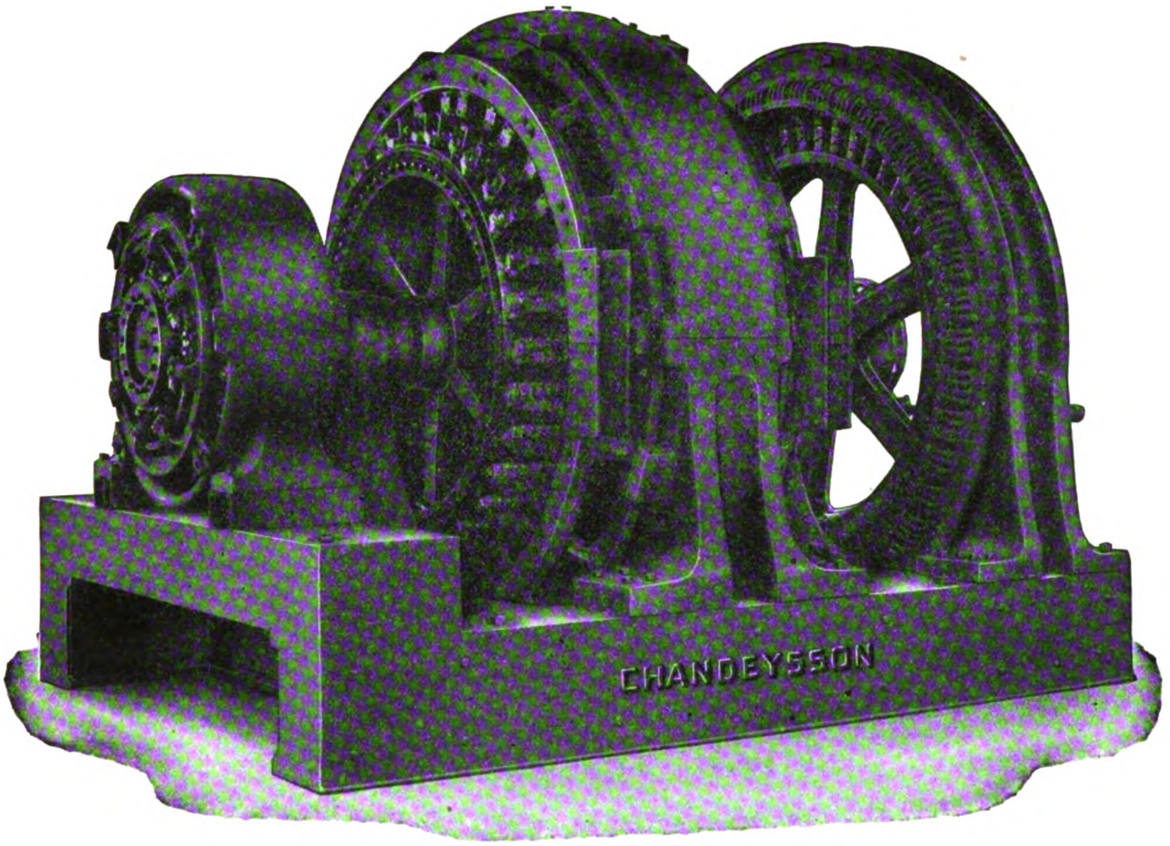
Chandeysson

Generators

25 to 25,000 Amperes

Direct Connected to

General Electric Motors

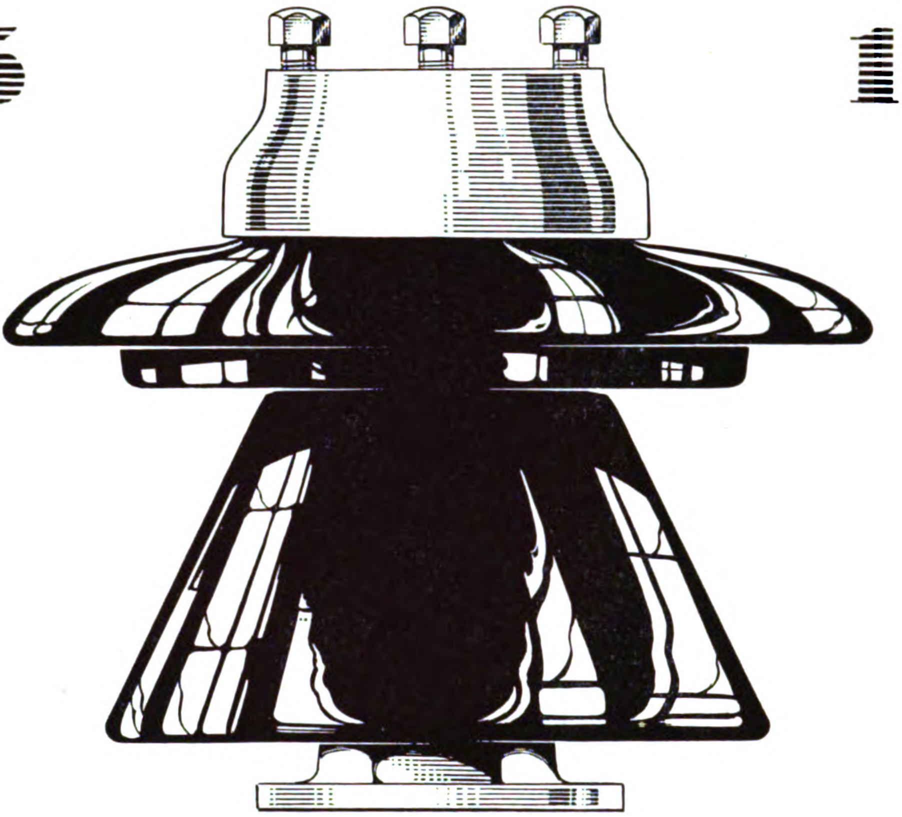


20,000 AMPERE 12 VOLT UNIT

WEIGHT 85,600 POUNDS

FABRICATED STEEL SUB-BASE

CHANDEYSSON ELECTRIC CO., St. Louis, U.S.A.



PERFORMANCE IS THE ONLY MEASURE OF QUALITY

QUALITY is only too frequently misunderstood even by those who talk most about it. No addition—no refinement is truly an indication of the quality of the product unless such refinements are reflected in increased satisfaction and improved performance.

In an insulator, as in all else, these are the only true guides by which quality may be determined. Highsounding processes and erudite theories are valueless unless they mean better service.

The reputation which Locke Insulators have won is based solely on the record for satisfactory service which they have established in the field for thirty-seven years.

That's quality.

LOCKE
PORCELAIN INSULATORS

LOCKE INSULATOR CORPORATION - - BALTIMORE, MARYLAND

ANNOUNCING—

Review of Progress in the Electrical Industry during 1930

THE JANUARY issue of the GENERAL ELECTRIC REVIEW will be devoted entirely to this subject—a thorough familiarity with which will furnish a flying start toward the solution of the engineering problems that will arise in 1931.

The following are some of the sections of the subject which will be covered in this summary of important developments:

- Steam Turbine Generators
- Meters and Instruments
- Photo-electric Control
- Waterwheel Generators
- Lightning Arrestors
- High-tension Cable
- Television
- Aviation
- Research
- Reactors
- Mining
- Radio
- Refrigeration
- Transformers
- Vacuum Tubes
- Steel Mills
- Switchgear
- Regulators
- Motors and Control
- Industrial Heating
- Electric Welding
- Carrier Current
- Marine Equipment
- Transportation

If your subscription for the REVIEW expires this month, or has already expired, send in your renewal without delay to be assured of receiving your copy of the January issue.

If you are not a subscriber, you can do no better than to send in your subscription to begin with this internationally-quoted number of our magazine.

As gifts for your friends who are interested in the electrical industry, we recommend this valuable issue and will mail copies direct to them upon receipt of your remittance of 30¢ a copy.

If you yourself need extra copies of the January issue, mail in your order NOW along with your remittance.

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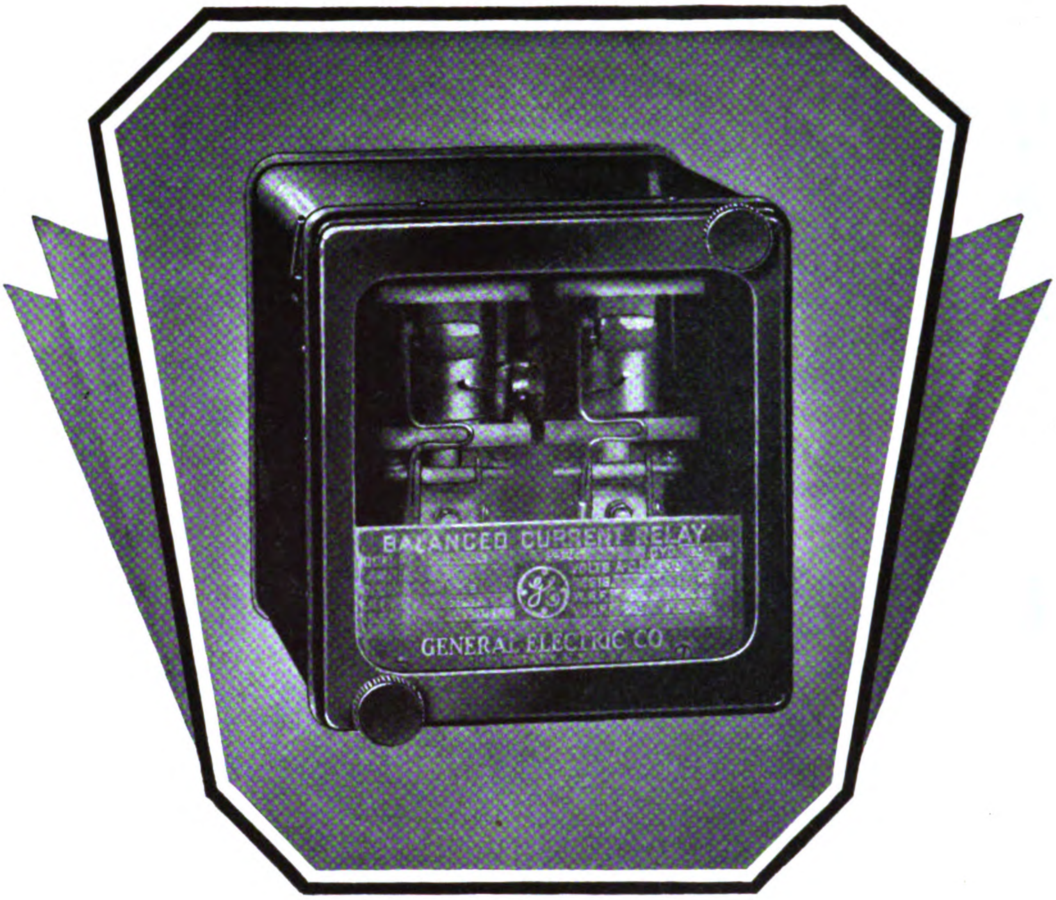
GENERAL ELECTRIC REVIEW

SCHENECTADY, N. Y.



Type RDC Relay
For Parallel-Line Protection

OPERATES IN $\frac{1}{120}$ SECOND

System stability can be maintained with RDC relays. These relays operate with such speed that they cause faulty lines to be disconnected almost at the instant of fault.

RDC relays are of the balanced-current type. They are used on high-voltage transmission lines of interconnected systems to function on grounds and phase-to-phase faults.

An outstanding feature of the Type RDC is the novel use of voltage restraint. By means of this, the relay is made extremely sensitive to fault currents much below normal system current. However, there is no false operation on through currents, or when one of the parallel lines which previously has been disconnected is put back in service.

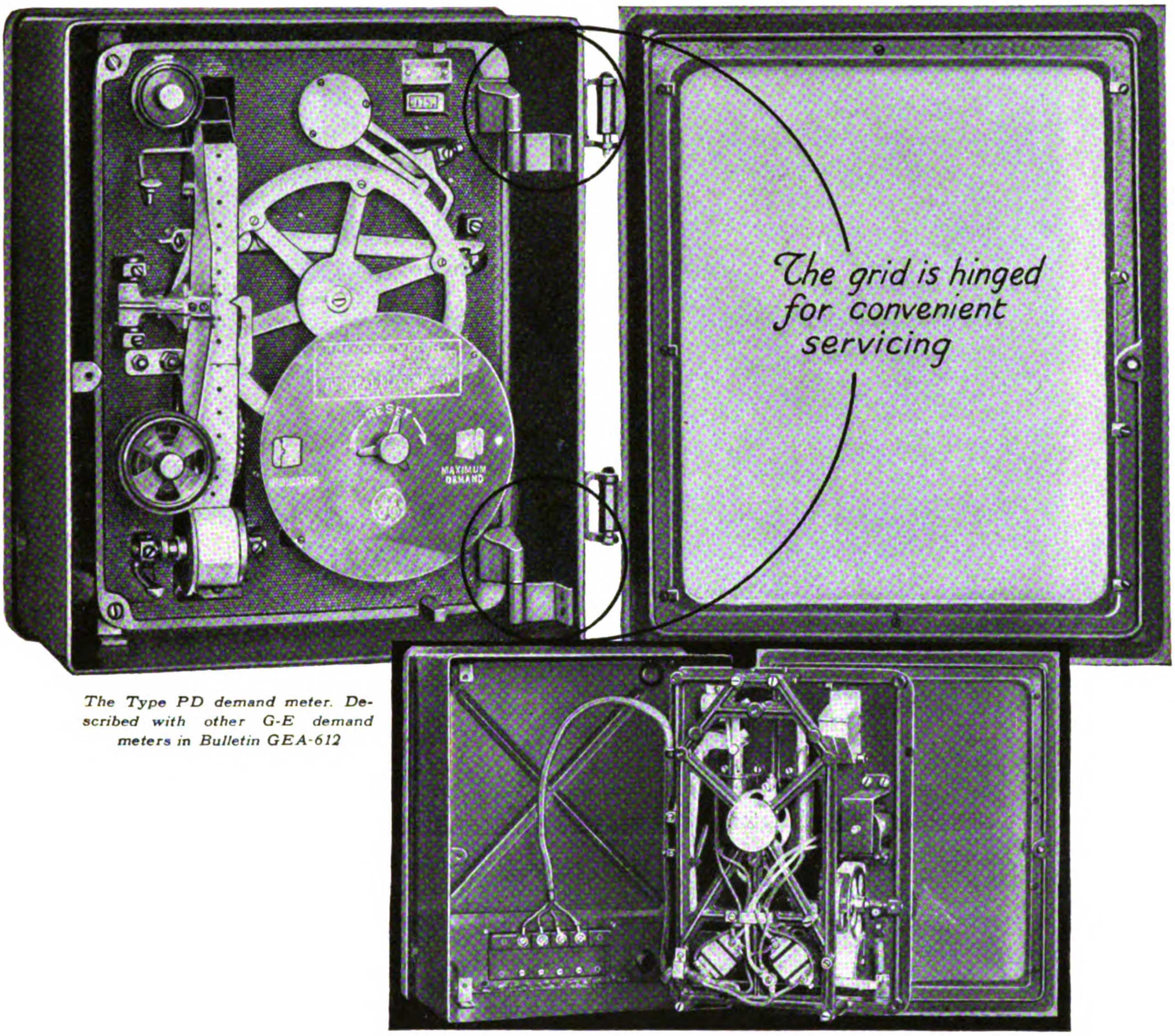
JOIN US IN THE GENERAL ELECTRIC PROGRAM, BROADCAST EVERY SATURDAY EVENING ON A NATION-WIDE N.B.C. NETWORK

500-57

GENERAL ELECTRIC

SALES AND ENGINEERING SERVICE IN PRINCIPAL CITIES

PRINTING-TYPE DEMAND METER FURTHER IMPROVED for your CONVENIENCE



The grid is hinged for convenient servicing

The Type PD demand meter. Described with other G-E demand meters in Bulletin GEA-612

Join us in the General Electric program, broadcast every Saturday evening on a nation-wide N.B.C. network

THE grid, or operating mechanism, of Type PD demand meters is now hinged so that, when servicing is necessary, it can be done much more conveniently. » » » Other refinements will contribute to reliability, notably a new bearing construction for the pawls that advance the type wheel. » » » But fundamentally, the popular Type PD demand meter remains the same—a high-grade device for important demand-metering jobs.

620-9

GENERAL ELECTRIC

SALES AND ENGINEERING SERVICE IN PRINCIPAL CITIES

satisfaction

SATISFACTION in printing is expressed in results. Unless your printing brings you increased business . . . greater profits . . . you are not satisfied. Your choice of a printer determines to a great extent, the success or failure of your advertising . . . whether or not your business succeeds or fails. Business does not "*hold its own*" in the keen competition of today.

Why not insure the success of your advertising by placing your printing problems in our hands? We are equipped to render you a *real* service . . . to give complete satisfaction. May we hear from you?

Printers
Engravers
Electrotypers
Binders

THE MAQUA COMPANY

SCHENECTADY - NEW YORK

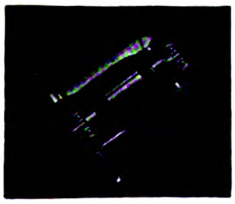
In Her Majesty's service!

"Ye Kynges and queanes of olden tymes" had at their command no such array of willing, efficient, cleanly helpers as those which today are in the service of Her Majesty, the American Woman.

Science and engineering have brought to the aid of the American housewife mechanical and electrical devices of many man-and-maid-power. And, in the seeking for greater effectiveness, greater simplicity, greater trouble-proofness and, above all, greater cleanliness, ball bearings have been employed to eliminate the messy oil can and to minimize the wearing-out factors.

OVER TWO MILLION BALL BEARING VACUUM CLEANERS THAT NEED NO OILING

Are in daily use in American homes today, running smoothly and sweetly on Norma-Hoffmann Precision Ball Bearings—a vast and growing army of ever-ready, willing, effective workers giving care-free, trouble-free, dirt-free satisfaction—*needing no oiling* because permanently grease-packed—earning good-will and confidence and approval for the progressive manufacturers who built them.



Are YOU manufacturing a vacuum cleaner that your customer need never oil—and which will need NO SERVICING?

"NORMA-HOFFMANN"

PRECISION BALL BEARINGS

1047

NORMA-HOFFMANN BEARINGS CORPORATION STAMFORD, CONN., U.S.A.

MIMAX LACQUER

MANUFACTURERS of electrical products find MIMAX Lacquer the most practical and profitable finish available .... practical because it speeds up production, offers better protection, wears better, serves its purpose longer .... profitable because it speeds up sales, improves appearance, stimulates demand.

Mimax was developed to meet the requirements of your industry. The PPG Research Laboratories, Paint Engineers, and Color Engineers will co-operate on any of your individual problems, offering counsel without cost or obligation.

PITTSBURGH PLATE GLASS CO.

Paint, Varnish and Lacquer Factories:

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Portland, Ore. Los Angeles, Calif.

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75
YEARS OF PROGRESS

1855 1930

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ESTABLISHED 1868

Water Tube Boilers
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Economizers
Air Preheaters
Chain Grate Stokers
Oil Burners
Refractories
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LOS ANGELES	Central Building
NEW ORLEANS	344 Camp Street
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PHOENIX, ARIZ	Luhr's Tower
PITTSBURGH	Koppers Building
PORTLAND, ORE.	Failing Building
SALT LAKE CITY	Kearns Building
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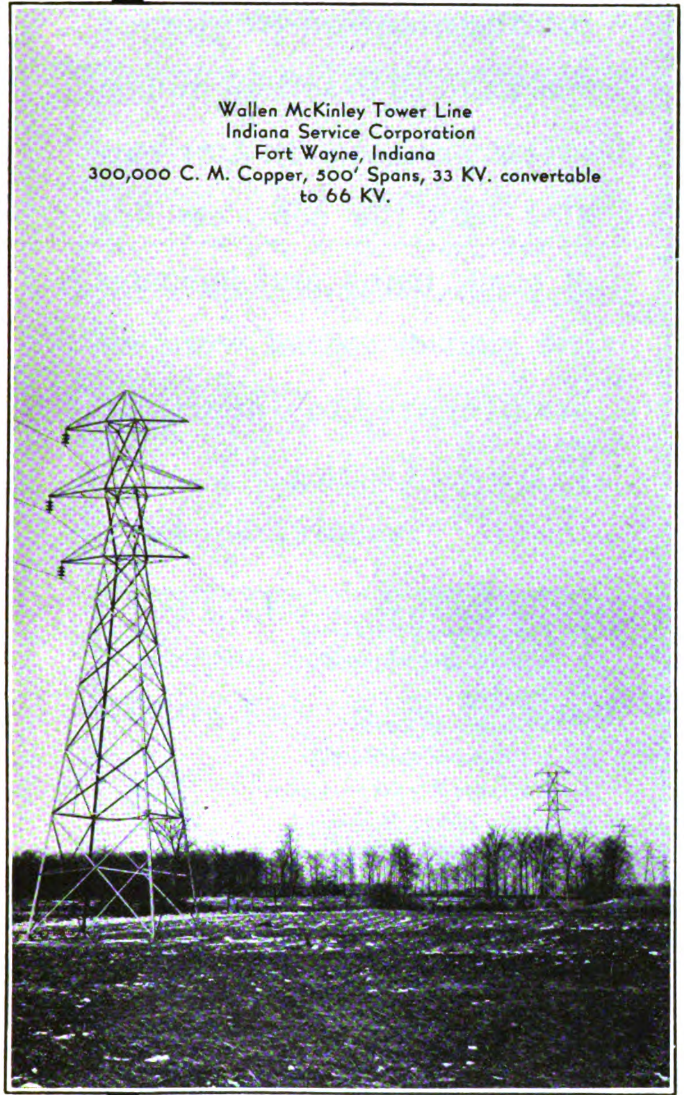
Before Christmas comes—

Now is the time to think of renewing your GENERAL ELECTRIC REVIEW subscription ere you are in the whirl of the Christmas season.

What better gift than a REVIEW subscription for a friend whom you should not forget

—when Christmas comes

TOWERS BY BLAW-KNOX



Wallen McKinley Tower Line
Indiana Service Corporation
Fort Wayne, Indiana
300,000 C. M. Copper, 500' Spans, 33 KV. convertable to 66 KV.

Manufacturers of Blaw-Knox Electroforged Steel Grating and Open Flooring

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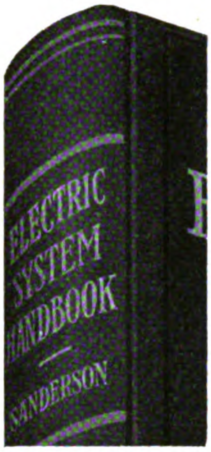
Your name stamped on this book FREE

At no additional cost to you, we will stamp your name, or a friend's name in gold on the front cover of every copy of Sanderson's Electric System Handbook ordered from this advertisement. This is a special Christmas offer, limited to acceptance before January 1, 1931.

for Engineers, Operators *and* Draftsmen—

a complete manual of electrical distribution practice

Here, in one comprehensive volume of more than a thousand pages, is the whole story of the electric system—everything you will want to know about the generation, transmission and distribution of electricity.



Electric System Handbook

Clarence Herbert Sanderson, Editor-in-Chief
Assistant Electrical Engineer, The New York Edison Company

1131 pages, 5x8, fully illustrated, $5.00 postpaid

HERE are the fundamentals of electricity. From these fundamentals this Handbook leads you through the details of the up-to-date electric system to the solutions of problems encountered in the design, construction, maintenance and operation of modern power systems. It discusses generating stations and generating—transmission—substations—transforming and auxiliary equipment—distribution—circuits and systems—electrical apparatus—inspection and maintenance of electrical equipment.

Numerous engineering tables—diagrams—charts and illustrations illuminate the text. Electrical words and terms are defined and explained. Everything is here. Every phase of the work is most satisfactorily treated for the engineer, the operator, the inspector, the draftsman, the maintenance and test department employee. The editor-in-chief writes with the authotity gained in many years of practical experience with electric systems. An equally valuable record of experience is behind each of the other seven contributors to this Handbook. They have omitted higher mathematics, and they have made all technical expressions clear

Do you want to make a friend a gift combining personal thoughtfulness with real utility? Do you want a copy of Sanderson that you will doubl prize? Then take advantage of this free stamping offer. Send the coupon today. (Proper remittance should be enclosed with orders, and, of course stamped copies are not returnable.)

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Send me Sanderson's Electric System Handbook with name stamped in gold on the front cover. I enclose $5.00 and understand that stamped books are not returnable. (This offer expires Jan. 1, 1931.)

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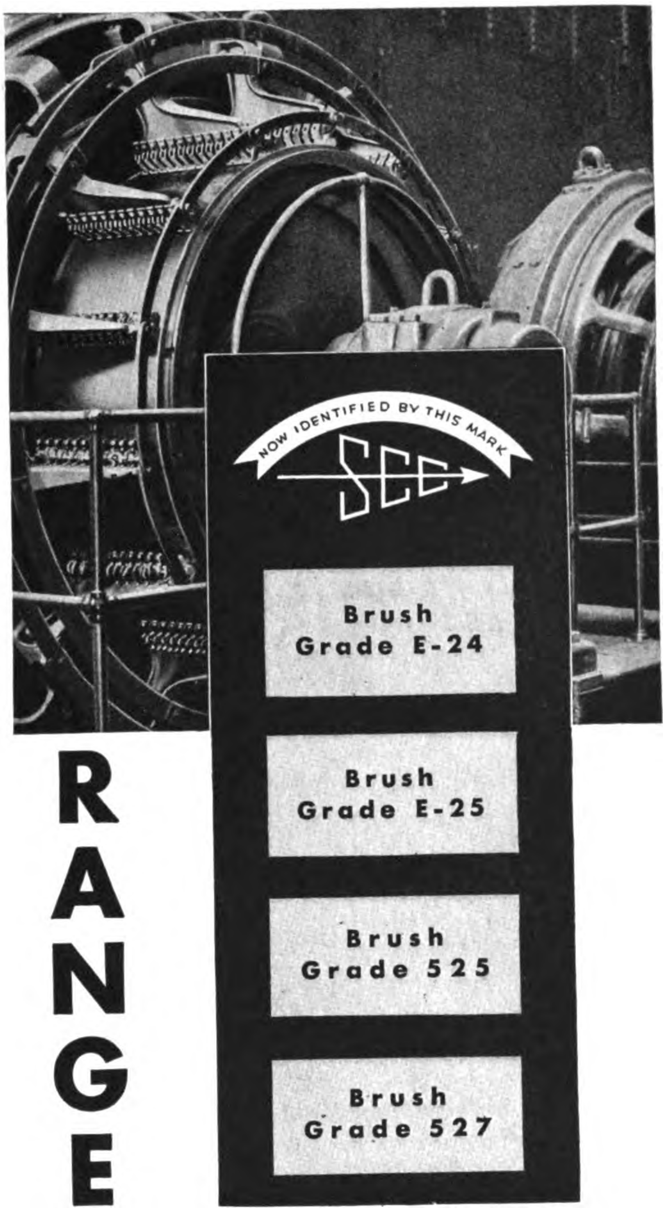

RANGE

The range of Speer grades is wide enough to meet all your brush requirements. This range includes brushes of the electro-graphitic, carbon-graphite, natural graphite and metal-graphite types, suitable for all standard and many special motors and generators, from the smallest fans to the largest power equipment.

Let us recommend the grade. Speer Brush Data Forms will find it for you. Write for yours.

SPEER CARBON COMPANY
Saint Marys, Penna.

Brush Grade 696

SPEER

4917

WE DESIGN and manufacture a variety of electrical instruments and accessories for making measurements in the communication-frequency spectrum (0 to several million cycles per second). Our catalog lists the complete line of stock items and indicates the kind of special work we are prepared to undertake. Write for Catalog F-G.

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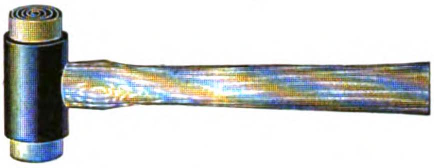
- Bridges
- Resistance Boxes
- Calibrated Inductors
- Variable Air Condensers
- Attenuation Networks
- Voltage Dividers
- String Oscillograph
- Thermionic and Oxide-Rectifier Voltmeters
- Rheostats, Transformers, Relays, etc.

GENERAL RADIO COMPANY
Manufacturers of
Electrical Measuring Apparatus for
Laboratory and Industrial Use
CAMBRIDGE A, MASSACHUSETTS



RAW HIDE

We have used this heading, wondering if you would be sufficiently interested to read about what we are making

In purchasing or using a Hide Faced Hammer or Raw Hide Mallet, probably very few understand the care used in selecting and preparing the Hides, which is the first step necessary to insure a satisfactory and service-giving article. Then comes the manufacture of the Hide into the following products:

Hide Faced Hammers
Raw Hide Mallets
Patent Raw Hide Mallets
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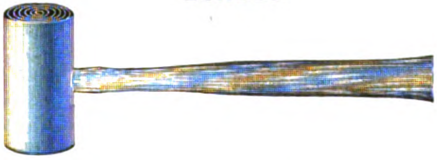

Made from Raw Hide and By Us

HOLBROOK
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Etsablished 1822

748 North Main St. Providence, R. I.

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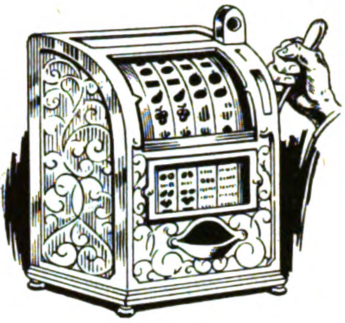
It is **RESULTS** that count

It is "Wicked" to Gamble with



WELDING WIRE

If there is anything worse than an unsatisfactory Welding Job we have never been able to discover it. Here you want reliability plus. And it is no place to gamble with mine-run materials.

Page-Armco Welding Wire costs a little more, it is true, but it is also worth more. There are no spoiled jobs, no wasted labor through lack of uniformity or inclusions which prevent uniformity in the finished work.

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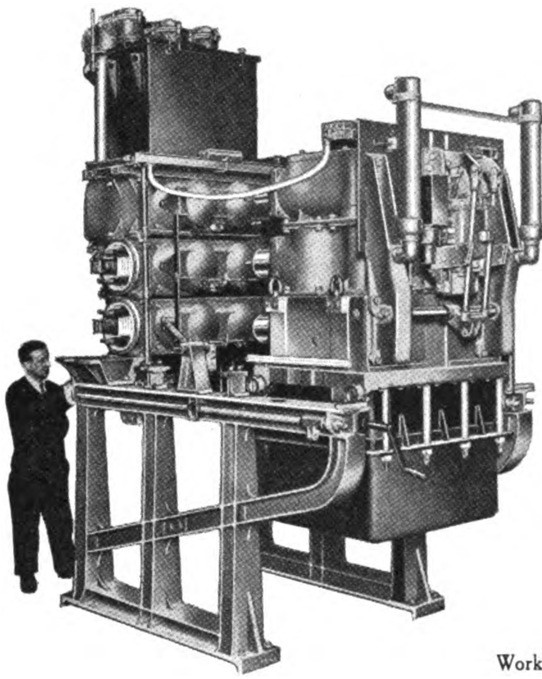

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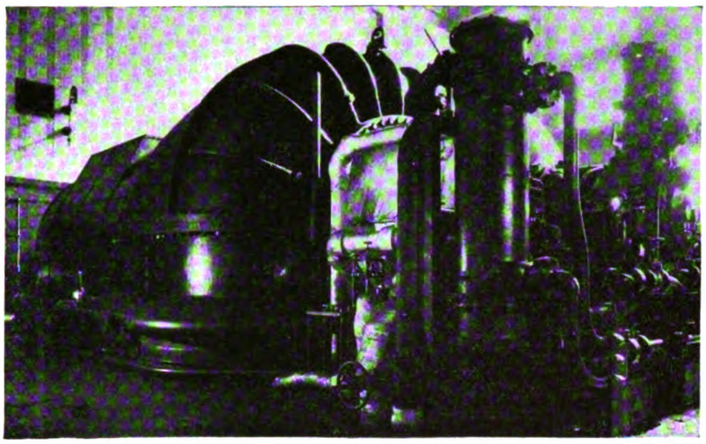

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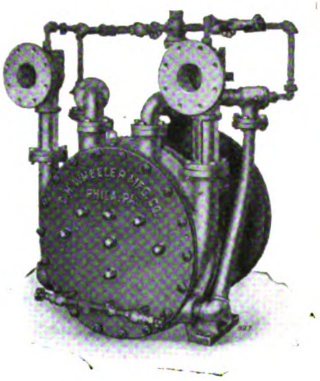

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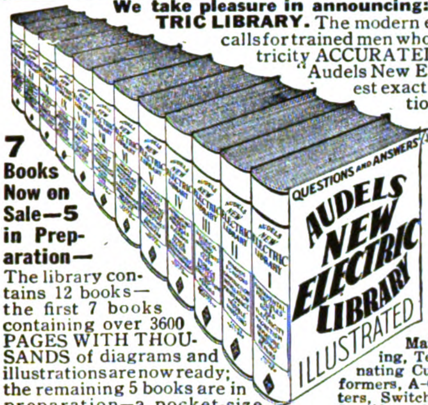

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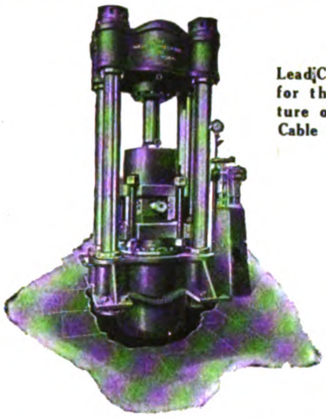

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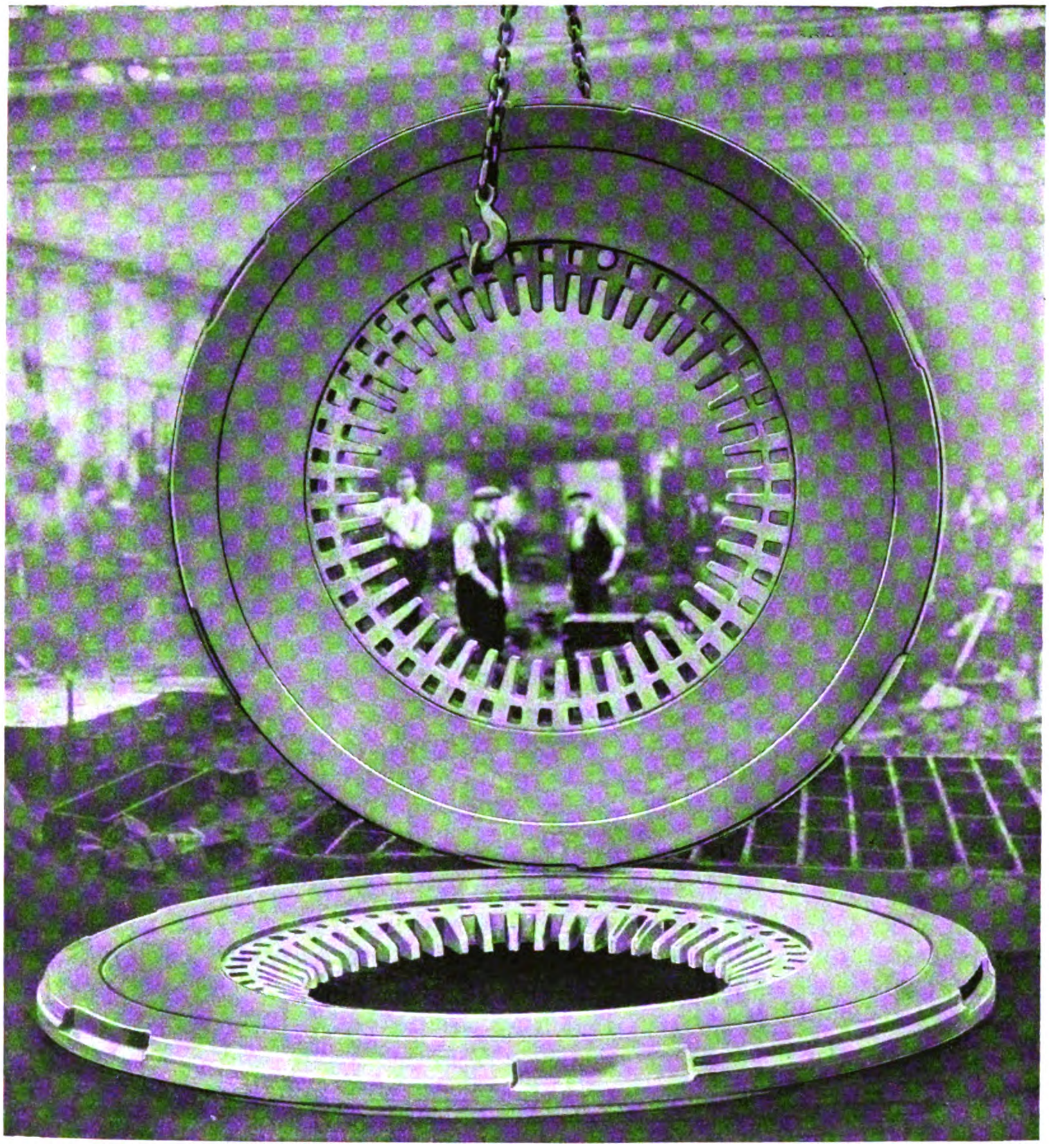

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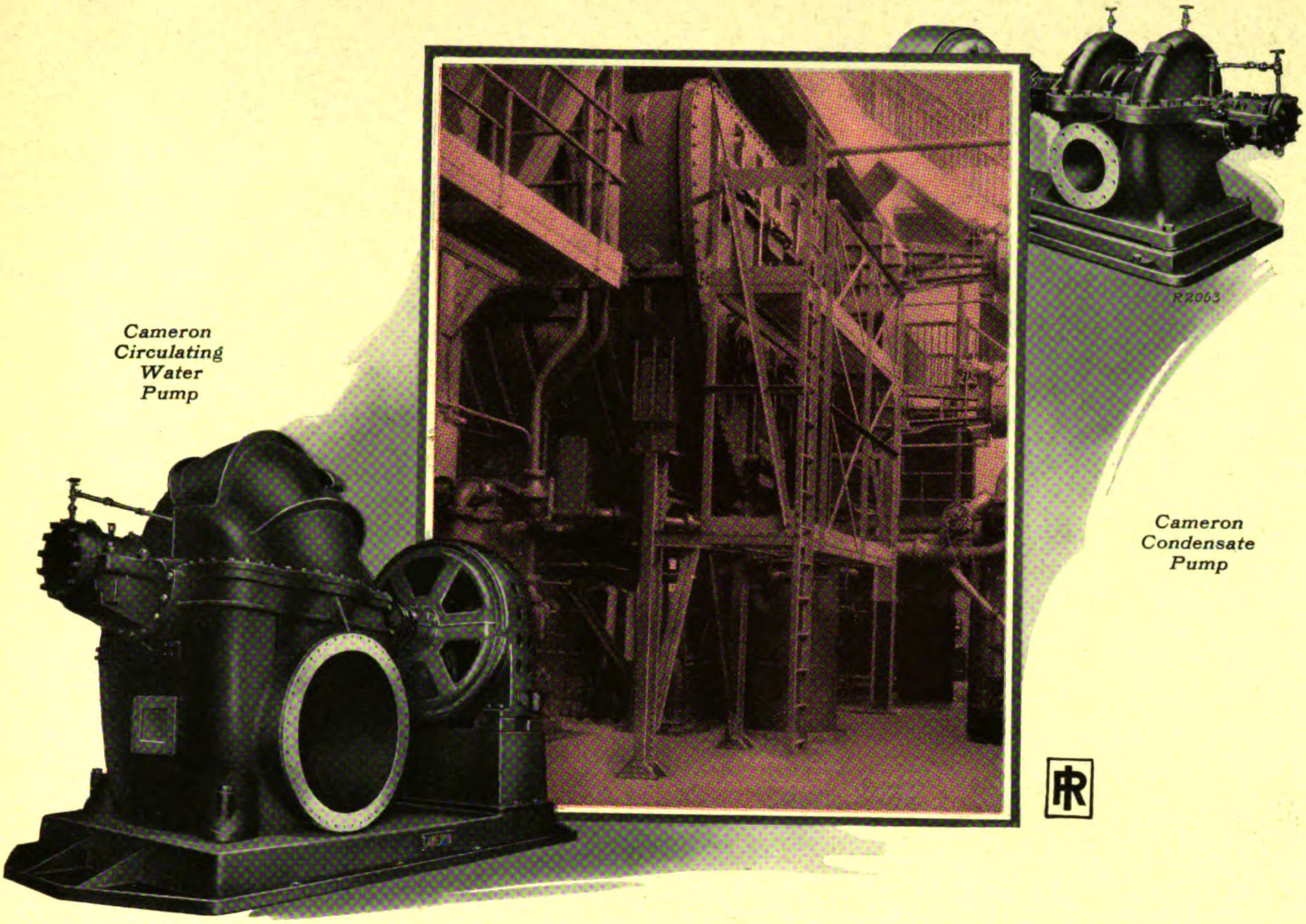

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